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THE SUPPLY OF MUNITIONS

PART I

GUNS

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CHAPTER I.

INTRODUCTORY.

I. The Sources of Supply.[1]

At the outbreak of war, experience of gun making in Great Britain was confined to the Royal Gun Factory at Woolwich Arsenal and to five armament firms—Messrs. Armstrong, Vickers, Cammell Laird, Beardmore and the Coventry Ordnance Works.

In 1904–5 orders had been placed for the re-arming of the artillery with the new types of field guns—13-pdr., 18-pdr., and 60-pdr. guns and 4·5-in. howitzers. The equipment of the Royal Horse Artillery with 13-pdrs. and of the Royal Field Artillery with 60-pdrs. was complete by 1907, while the deliveries of 18-pdrs. were completed two years later. The provision of the new 4·5-in. field howitzer began in 1908 and the bulk of the deliveries were made in 1910–11, though production at the Ordnance Factories continued until the outbreak of war. Thus, only in the case of the 4·5-in. howitzer was there any substantial output of land service guns during the five years immediately preceding the war.[2]

With regard to guns other than field guns, two 9·2-in. guns were delivered in March, 1913, and one 9·2-in. howitzer made by Messrs. Vickers in June, 1914. A few 6-in. guns were made between 1911 and 1914, by the Ordnance Factories, which also produced some 2·75-in. guns.

The Ordnance Factories alone had experience of all types of land service guns and the only field guns which had been produced for home service since 1909 were supplied by the Royal Gun Factory. Between 1911 and 1914, the Ordnance Factories manufactured 96 18-pdrs., 82 4·5-in. howitzers, and 12 13-pdrs., but most of these were sent overseas.[3] In August, 1914, there were uncompleted contracts at Woolwich for 18-pdr. guns, 4·5-in. howitzers, and 6-in. Mark VII guns, deliveries on which continued during the first few months of the war.

Of the armament firms, Messrs. Cammell Laird's last deliveries of land service guns had been made in 1909; those of Messrs. Armstrong and the Coventry Ordnance Works in 1911. Messrs. Beardmore delivered the two 9·2-in. guns mentioned above in March, 1913, while Messrs. Vickers were working on Canadian orders up to the outbreak of war.[4]

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[1] Hist. Rec./H/170/7; *Order and Supply Lists.*
[2] Hist. Rec./H/170/7.
[3] Hist. Rec./R/1000/54.
[4] The armament firms did a far greater proportion of the naval work; between 1908 and 1913, three-quarters of the total Admiralty expenditure on armaments was in respect of supplies from the trade.

The firm which had manufactured the greatest number of types was Messrs. Armstrong, who had made 13-pdr. and 18-pdr. guns and 4·5-in. howitzers and were in addition the only trade contractors with experience of 60-pdr. guns. Messrs. Cammell Laird had made 13-pdrs. and 18-pdrs; the Coventry Ordnance Works had concentrated on 4·5-in. howitzers, the first order for which was placed with them in 1908; and Messrs. Beardmore had done no land service work other than the 9·2-in. guns. Messrs. Vickers, having made 13-pdr., 18-pdr., and 4·5-in. for home service before 1911, had also produced 24 13-pdrs. for Canada in 1911, and 44 18-pdrs. in 1911 and 36 in 1914. Further, they had accepted an order for 24 4·5-in. howitzers in 1912, and of these 10 were still undelivered at the outbreak of war.

For some time after the outbreak of war, manufacture of land service guns in Great Britain was undertaken only by the Ordnance Factories and the four armament firms, Messrs. Armstrong, Vickers Beardmore and the Coventry Ordnance Works, Messrs. Cammell Laird concentrating on naval work. By the end of the first week of August, 1914, arrangements had been made for a large expansion of field gun manufacture at Woolwich, while by the end of August Messrs. Armstrong, Vickers, and the Coventry Ordnance Works had been given orders, Messrs. Beardmore being also drawn in six weeks later. Before the Ministry of Munitions became responsible for supply, moreover, orders had been placed with the Bethlehem Steel Company of America, and this firm was employed by the Ministry on a considerable scale, while in 1915 another American firm, the Midvale Steel Works, began manufacture for the Allies, receiving British orders from time to time. During the latter years of the war, also, as will be seen, other British firms took up gun work to a considerable extent.

The Ordnance Factories and the four armament firms, however, remained throughout the principal sources of supply. With the exception of certain heavy howitzers, the Ordnance Factories made at some period during the war, practically every type of gun required by the Army. As time went on, however, Woolwich was used increasingly for experimental work, experimental equipments being made and modifications first introduced there. Until the middle of 1916, moreover, all repair work was carried out at Woolwich, and this in addition to the new manufacture undertaken both for land and naval services made very heavy demands on the Gun Factory and Carriage Department.

Of the armament firms, the Coventry Ordnance Works concentrated mainly on 4·5-in. howitzers, but they also produced some 15-in., 12-in. and 6-in. howitzers. Messrs. Vickers, who were the only British contractors for the 9·2-in. howitzer, also made other heavy howitzers, such as the 12-in., 8-in., and 6-in., as well as 18-pdr. guns. Messrs. Armstrong were the chief source of supply for 60-pdr. guns; other types undertaken by them included 12-in. and 8-in. howitzers, 9·2-in., 6-in. and 18-pdr. guns. Messrs. Beardmore had large orders for 18-pdrs. and also made 9·2-in. and 6-in. guns, 8-in. and 6-in. howitzers. In addition to the manufacture of gun bodies or complete equipments,

all the firms made parts of many other types, while their repair work was also of the greatest importance during the latter part of the war.

II. The Position in June, 1915.

During the first months of the war there were available for use in the field 1,363 field guns of the new types (996 18-pdr., 185 13-pdr., 144 4·5-in., 38 60-pdr.). This total included the equipment of the original Expeditionary Force of 6 Divisions (*i.e.*, 324 18-pdr., 36 13-pdr., 108 4·5-in. and 24 60-pdr.) together with a number of guns taken from batteries stationed abroad, from training brigades, or from reserves, or brought over by Dominion and other overseas forces in August, 1914. In addition to these modern guns, there was the equipment of the Territorial Army, the 15-pdr. Q.F. and B.L.C. field guns, the 4·7-in. gun and the 5-in. howitzer. Considerable use was made of these obsolescent types, at first in France and later in the minor theatres of war, the numbers used being approximately 20 15-pdr. Q.F., 228 15-pdr. B.L.C., 80 5-in. howitzers and 88 4·7-in. guns. With regard to heavy guns a few only were available. Sixteen 6-in. Mark VII guns were taken from coast defences and placed on extemporised railway mountings, the first 8 being sent to France in January, 1915. A single brigade (24) of 6-in. 30 cwt. howitzers was in existence, but about 80 more were collected from various garrisons and colonial stations and despatched to the front. The one 9·2-in. howitzer, which had been approved in June, 1914, was sent to France as soon as ammunition could be provided, being until February, 1915, the only heavy howitzer at the front.[1]

On the outbreak of war immediate steps were taken to supplement the existing stocks of guns. During the ten months before the establishment of the Ministry of Munitions orders were arranged by the War Office with the Ordnance Factories and the trade on a scale which involved an enormous expansion of capacity, and this could not in the nature of things bear fruit for many months. The contracts made before the end of 1914 were intended to secure an increasing output during the first half of 1915, most of them being due for completion by the end of June, but the estimates of delivery on which the War Office relied were unduly optimistic, and when the Ministry of Munitions took over responsibility for supply, there was a large balance of deliveries still to come on War Office orders.

The outstanding features of this period were, first, the progressive increases in the orders for the field guns required to equip the new armies, which were being rapidly recruited ; and second, the placing of contracts for the heavy howitzers needed to attack the German fortified positions, these orders anticipating the demand of the Army in the early months of 1915 for guns with which "to keep down the enemy's long range artillery fire." Some account of the War Office orders for the various types of guns is given below.[2]

[1] HIST. REC./H/170/6.
[2] Chapter V. *See also* Vol. I, Part I.

The position in June, 1915, with regard to deliveries on these orders can be seen from the table below.[1] This shows the total number of guns contracted for between August, 1914 and the end of June, the actual deliveries on these orders at the beginning and end of June, compared with the number hoped for, and the balance remaining for delivery. It also shows the number of new guns issued to service before 30 June. The figures given for deliveries include guns under inspection as well as those approved, and the numbers of guns and carriages are shown separately, since, as will be seen, the carriages were apt to lag behind the guns, thus diminishing the number of complete equipments available for service use. The last column (issues to service) represents guns finally approved and issued to the War Office, and the figures are therefore as a rule slightly less than those for deliveries. In the case of 4·5-in. howitzers and 18-pdrs., however, the issues to service include some deliveries on pre-war orders, and the figures for these natures are therefore not comparable with those given in the preceding columns, which are for war orders only.

POSITION IN JUNE, 1915, ON ORDERS PLACED SINCE THE OUTBREAK OF WAR.

Type of Gun.	Orders placed August, 1914, to June, 1915.	Actual Deliveries to 31/5/15.		Actual Deliveries to 30/6/15.		Due on 30/6/15.	Balance outstanding on War Office orders after 30/6/15.		Issues to War Office to 30/6/15.
		Guns	Mountings	Guns	Mountings		Guns	Mountings	
13-pdr. ..	218	—	—	—	—	—	218	218	—
18-pdr. ..	3,628	882	604	1,096	803	2,338	2,532	2,625	802
4·5-in. How.	530	126	122	176	165	530	354	365	209
60-pdr. ..	160	42	19	47	37	108	113	123	33
6-in. How. ..	16	16	—	—	—	—	16	16	—
8-in. How. ..	24	24	24	24	24	24	—	—	24
9·2-in. How.	32	16	17	20	18	24	12	14	18
12-in. How...	32	5	5	8	6	21	24	26	5
15-in. How...	8	4	4	5	5	5	3	3	5

The table above deals only with those natures of guns for which additional output had been arranged since the outbreak of war. It has been seen that in two cases (4·5-in. and 18-pdr.), some deliveries were made on pre-war orders during the period under review. This is also true of 9·2-in. and 6-in. Mark VII guns, for which no new orders had been placed by the War Office. By the end of June, 1915, three 9·2-in. guns and six 6-in. guns had been delivered on pre-war orders, the former by Messrs. Beardmore, the latter by the Ordnance Factories.[2]

Further, in attempting to review the position of gun supplies in June, 1915, it is necessary to take into account the guns which were in existence on the outbreak of war.[3] The following statement therefore shows the stocks of pre-war guns, together with deliveries since August, 1914, the sum of which approximates to the total number of guns available on 30 June, or shortly after, for service in the various theatres of war. The figures given for new deliveries are those of issues to the War Office of finally approved guns.

[1] HIST. REC./H/1200/7, and *Lists of Orders for Guns, Carriages and Vehicles for use in the Field, and Siege Equipments* (A.2, War Office).
[2] HIST. REC./H/1200/7.
[3] *See* above p. 3.

Type of Gun.	Available at Outbreak of War	New Deliveries.	Total.
13-pdr.	185	—	185
15-pdr. Q.F.	20	—	20
15-pdr. B.L.C.	228	—	228
18-pdr.	996	802	1,798
4·5-in. Howitzer	144	209	353
4·7-in. Gun	88	—	88
5-in. Howitzer	80	—	80
60-pdr. Gun	38	33	71
6-in. Mark VII. Gun	16	6	22
6-in. 30-cwt. Howitzer	104	—	104
8-in. Howitzer (converted) ..	—	24	24
9·2-in. Gun	2	3	5
9·2-in. Howitzer	1	18	19
12-in. Howitzer	—	5	5
15-in. Howitzer	—	5	5

CHAPTER II.

DEVELOPMENT OF THE GUN PROGRAMME, JUNE TO DECEMBER, 1915.

I. Gun Programme "A."

On 19 and 20 June, 1915, an important conference was held at Boulogne between Mr. Lloyd George, the newly-appointed Minister of Munitions, M. Thomas, French Under Secretary of State for Munitions and other French and British representatives.[1] Among other matters, the conference considered the requirements of the Allied Armies for guns and ammunition, and the discussion which took place revealed the need for a largely increased supply of heavy artillery for the British forces.

On 22 June, Lord Kitchener telegraphed to Sir John French stating that an increase of heavy ordnance was being considered. Orders already placed, and guns then in the field would give the following totals :—

32	12-in. Howitzers.
48	9·2-in. Howitzers.
32	8-in. Howitzers.
80	6-in. Howitzers (old pattern).
64	6-in. Howitzers (new pattern).
180	60-pdr. Guns.

To create a homogeneous army he thought that further orders might be placed in the following proportions :—

32	9·2-in. Howitzers.
80	6-in. Howitzers.
100	60-pdr. Guns.

He asked Sir John French to give his views fully, with any additions and modifications he might think desirable.[2]

Sir John French's reply,[3] (25 June, 1915) showed the results of the Boulogne Conference. He first outlined the position of the French and German Armies with regard to heavy ordnance. From the latest information in his possession, the German Army in the middle of May had 7,150 field guns and howitzers, including 4·13-in. howitzers, and 3,350 heavy guns and howitzers (5·9-in. and over), exclusive of heavy Austrian howitzers attached to the German Army. At the outbreak of war, the German Army was armed with an obsolescent field gun, but instead of remedying this defect, all their efforts had been directed

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[1] For the official report of the Conference, *see* Vol. II, Part VIII, Appendix I.
[2] 5696 Cipher in D.M.R.S. 30.
[3] O.B/19/2 in D.M.R.S. 30.

towards developing their heavy artillery. They had allowed the proportion of field guns to fall to 3·5 per 1,000 bayonets, while the proportion of heavy guns was then 1·7 per 1,000 bayonets, so that approximately one-third of their total guns were of 5·9-in. calibre and over. Their field guns fired comparatively little, and the enormous number of projectiles fired by them whenever important operations took place were mostly of 5·9-in. and upwards, these heavy shells being used for defence as well as attack.

With regard to the French equipment, the French representatives at the Boulogne Conference had stated that they aimed at obtaining one heavy gun, 6-in. or upwards, for every field gun in the field, without reducing the existing proportion of field guns to bayonets, and had repeatedly emphasised the fact that demands from the front were for "more guns, for heavier guns, and for more ammunition for heavy guns." To meet this demand, they were taking guns from their old warships and from coast defences, and were straining every nerve to get guns of heavier calibre into the field. Sir John French had further ascertained that the French were not reducing the proportion of 75mm. guns, but were allowing all medium guns to drop out, and had already obtained a proportion of one heavy to four field guns along the whole front, while on portions of the front where active operations were being conducted the proportion was approximately one to three.

The letter then continued:—

"Comparing the above with the situation of the British Army, I find that I have at my disposal at the present time:

	Guns.
Field Guns	1,080
Guns and Howitzers, between 4·5-in. and 5-in. calibre (both inclusive)	336
Guns and Howitzers, 6-in. and upwards ..	71
Total	1,487

"This gives a proportion of 5·7 guns of all calibres, per 1,000 bayonets in this country. This proportion is satisfactory, but in view of the large increase in heavy guns that is obviously necessary it seems doubtful whether the proportion of lighter natures can or should be maintained. Both the French and the Germans appear to favour the elimination of the medium weapons, but in view of the admirable work that has been done by the 60-pdr. and 4·5-in. howitzer, I am not prepared to adopt this view, and it appears to me clear that these natures must be maintained. In fact, only in the event of the necessary expansion of the heavy artillery (6-in. and upwards) and the maintenance of an adequate ammunition supply for these heavy guns and howitzers necessitating such a step, would I advocate disturbing existing establishments of our Divisional Artillery. I should be quite content to see the 15-pdr. B.L.C., and the 4·7-in. drop out, but would retain the 5-in. howitzer, as with the 40-lb. projectile that is to be supplied, I understand that it is likely to prove a very satisfactory weapon.

"We come then to the main question of the number of heavy guns and howitzers that should be provided, and after full consideration, I have decided to submit the following proposals:—

(*a*) That every effort be made to provide before the conclusion of this summer campaign sufficient 60-pdrs. to replace all 4·7-in. guns now in this country, and to send out a 60-pdr. battery for every reinforcing Division that comes out.

(*b*) That the 6-in. howitzer batteries be brought up to a proportion of 1 per Division as soon as possible, and that a battery be sent out for every reinforcing Division.

(*c*) That a Brigade (2 batteries) of either 8-in. or 9·2-in. howitzers be provided for every Corps of three Divisions as soon as possible.

(*d*) That a battery of 12-in. or 15-in. howitzers be provided for every Army of three Corps, as soon as possible.

(*e*) That during the winter no effort be spared to double this proportion, so that by the spring of 1916, should the war continue so long, we may have:—

2 batteries 60-pdr. per Division.
2 batteries 6-in. Howitzers per Division.
4 batteries 8-in. or 9·2-in. Howitzers per Corps.
2 batteries 12 in. or 15-in. Howitzers per Army of three Corps.

"Taking it, then, as possible that the Army may expand to 50 Divisions by the spring (March) of next year, the number of heavy guns in the field would be, according to the above:—

60-Pdrs.	400
6-in. Howitzers	400
8-in. or 9·2-in. Howitzers	250
12-in. or 15-in. Howitzers	40
Total	1,090

This would bring us to a position approaching that occupied by the Germans to-day in proportion to their numbers.

"It follows that the provision foreshadowed in your telegram under reply does not, in my opinion, suffice to meet requirements based on the assumed expansion referred to above.

"I may add that experience has shown that rapidity of fire is not essential for heavy howitzers, and that extemporised mountings, such as that provided for the 8-in. howitzer, answer the purpose satisfactorily."

On 30 June the War Office forwarded Sir John French's letter to the Ministry, asking for their observations, and stating that if the Ministry was able to provide enough heavy artillery to meet Sir John French's request, some further guns would be necessary to complete the equipment of the forces in the field and to provide for wastage and reserve.[1] Annexed to the letter was the following table showing the number of guns required for a force of 70 Divisions, the number that were in existence or on order, and the balance to be provided by the Ministry:—

[1] 121/Stores/2848 in D.M.R.S. 30.

	Required.	In existence or on order.	Balance required.
60-pdr. Guns	800	200	600*
6-in. Howitzers	560	160 (Includes 48 now under negotiation)	400
9·2-in. or 8-in. Howitzers ..	372	80	292†
12-in. or 15-in. Howitzers ..	60	40 (?)	20
Totals..	1,792	480	1,312 For wastage and reserve.

* We may improve some 100 of the 4·7-in. to help in this.

† The Navy may be able to give us some 6-in. to convert into 8-in. howitzers. (On 13th July, the Master-General of the Ordnance stated that 40 more 6-in. naval guns would be available for conversion. D.M.R.S. 55.)

The requirement for field guns (18 pdrs. and 4·5-in. howitzers) was given by the Director of Artillery, in a minute of 2 July, as follows :—

3,407 18-pdr. guns by 30 June, 1916.

1,284 4·5-in. howitzers by 30 June, 1916.

His figure for 60-pdr. guns (752) varied from that given on 30 June, and he stated that it was possible that only 652 instead of 752 would be required if satisfactory improvements were made to the 4·7-in guns. Ammunition was to be provided according to a monthly scale to correspond with the number of guns in the field, rising by July, 1916, to 2,520,000 rounds of 18-pdr. ammunition, 672,000 rounds of 4·5-in. ammunition and 336,000 rounds of 60-pdr. ammunition per month.[1]

The Ministry, on 8 July, asked the War Office for some further information as to the number of guns required per Division, per Army Corps of three Divisions, and per Army of three Army Corps, with the percentage of wastage in the field and the percentage requiring repair per week, and the number required for reserve and training. On 16 July the War Office replied that the number of guns asked for included those required for wastage and reserve. The organisation of Army Corps and Armies had not been authoritatively laid down and was liable to vary according to circumstances, the Division being the largest unit for which any war establishment was laid down.[2]

In the meantime the gun makers had been called together to find out how far it was possible to meet the new demands of the War Office. Conferences were held on 5 July and 9 July, at which the gun makers were asked what they hoped to be able to deliver. Mr. Lloyd George emphasised the importance of completing the programme by the spring of 1916. The firms made certain promises, which were discounted by the Ministry in view of experience of the shortage of deliveries on War Office orders, and these discounted promises formed an estimate of probable deliveries, which representatives of the Ministry laid before the War Office on 13 July.[3]

[1] For gun ammunition programmes, *see* Vol. X, Part II.

[2] 121/Stores/2920 in D.M.R.S. 33.

[3] D.M.R.S. 55. The meeting was attended by Major-Generals Sir S. B. von Donop, J. P. Du Cane, and H. Guthrie Smith, and Lt.-Col. B. R. Kirwan, on behalf of the War Office, while Sir Frederick Donaldson (C.S.O.F.), Sir Percy Girouard, Mr. Ellis, Major Symon and Mr. Layton represented the Ministry.

Sir Percy Girouard considered that it was impossible to provide the number of guns asked for by 31 March, 1916. The only natures in which estimated deliveries would reach requirements by that date were 18-pdr. guns and 12-in. and 15-in. howitzers. The maximum required would not be reached even at the end of September, when there would be 167 60-pdr. guns, 147 6-in. howitzers, and 158 8-in. and 9·2-in. howitzers outstanding. Further, owing to the uncertainty of deliveries of machinery, and the difficulty of obtaining skilled labour, it was possible that even these estimates would not be reached, particularly in the case of 60-pdrs. and 9·2-in. howitzers, but they were put forward as the basis on which ammunition might reasonably be provided. The Master-General of the Ordnance then requested Sir Percy Girouard to proceed with arrangements for providing the number of guns and equipments asked for.

When asked if orders should be placed for guns in excess of the numbers that could be delivered by September, 1916, the Master-General of the Ordnance stated that an option should be obtained from gun makers for delivery of the total number of guns in the full programme, but suggested that the Ministry of Munitions should approach the War Office in about six months time to ascertain if delivery was still required of the guns outstanding after September, 1916.

The following table summarises the differences between requirements and anticipated deliveries as stated at this meeting.

Name.	Number required (in addition to stocks existing on 30 June, 1915).		Estimated deliveries.		Deficiency for subsequent delivery.
	By 31 March, 1916.	By June 30, 1916.	To 31 March.	To 30 Sept.	
18-pdr.	2,680	3,407	2,680	3,407	Nil.
4·5-in. Howitzer	1,000	1,284	667	1,284	Nil.
60-pdr.	560	752	247	585	167
6-in. Howitzer ..	474	474	83	327	147
8-in. Howitzer	330	330	8	8	158
9·2-in. Howitzer			48	164	
12-in. Howitzer	55	55	47	47	Nil.
15-in. Howitzer			8	8	

The general lines of the gun programme were therefore settled at this meeting, and on the following day (14 July) the War Office sent in a monthly statement of requirements both for guns and ammunition,[1] which, with the information already before the Ministry, formed the basis of the programme known as Gun Programme "A."

The programme provided for a maximum of 8,881 pieces of all calibres, of which 7,240 were to be in the field by the end of March, 1916. Certain types of gun which were obsolescent were to disappear from the service at various dates. No new 15-pdr. guns were to be made, and the 15-pdr. guns in the field were to be withdrawn in December, 1915. The 5-in. howitzer and the 4·7-in. gun were to be withdrawn during 1916, and no new guns of these types were to be ordered. The following table gives the details of the programme :—[2]

[1] D.M.R.S./46. On 20 July the Ministry pointed out that it was still without information as to the number of 13-pdr. guns required, and that M.G.O's minute of 2 July had made no distinction between 13-pdr. ammunition for H.A. and A.A. guns. (D.M.R.S./33.)

[2] HIST. REC./R/1000/123/1.

GUN PROGRAMME "A."[1]

Type of Gun.	Stock on June 30, 1915.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March.	Maximum
18-pdr. ..	1,700	1,940	2,200	2,480	2,780	3,100	3,420	3,740	4,060	4,380	5,107
15-pdr. ..	228	228	228	228	228	228	228	—	—	—	—
13-pdr. ..	114	136	145	155	172	192	212	242	272	312	356
4·5-in. ..	334	418	476	536	596	656	806	966	1,150	1,334	1,618
5-in. ..	80	80	80	80	80	80	80	80	80	80	—
60-pdr. ..	68	131	162	192	264	336	408	480	552	628	820
4·7-in. ..	88	88	88	88	88	88	88	88	88	88	—
6-in. Gun ..	8	12	20	24	24	24	24	24	24	24	—
6-in. How ..	86	48	64	80	88	92	100	108	132	192	560
8-in. ..	24	16	24	24	24	28	32	40	48	56	60
9·2-in. ..	18	16	26	30	34	42	53	66	82	102	312
12-in. ..	1	2	6	12	16	20	28	32	40	44	48
15 in. ..	4	—	—	—	—	—	—	—	—	—	—

II. Gun Programme "B."

In the meantime Sir John French had written another letter to the War Office (8 July), which, with the tables attached to it, contained a fuller statement of requirements, based as before on an establishment in the field of 50 divisions in the spring of 1916.[2] The figures, therefore, were smaller throughout than those of the War Office, which had been based on 70 divisions at the end of March. Sir John French stated that they had been worked out on the assumption that the Army would be reinforced gradually, and that a sudden rise in the output of ammunition did not appear probable. He recognised that they had been compiled with inadequate knowledge of manufacturing possibilities, and could only be considered tentative suggestions. As they might not be easy of interpretation by themselves, he proposed that Major-General Du Cane should go home to place his knowledge of the requirements of the Army at the disposal of the new Department.[3] The table ("A"), which dealt with the monthly reinforcement of guns, is printed below (page 12).

The letter emphasised the need for early deliveries.

> "It is of the greatest importance, however, that the rate of supply should be speeded up as much as possible, to enable me to develop the full value of the Army under my command at the earliest date."

After further inquiries the Ministry was able to improve on the estimates of gun deliveries given in Gun Programme "A," especially with regard to 60-pdr. and 6-in. howitzers. Gun Programme "B" (page 13), which was put forward on 28 July, anticipated that the full requirements of heavy guns might be met in 1916, the deliveries of 12-in. and 15-in. being completed as before by 31 March, 1916, the 6-in. howitzers by 30 September, 1916, the 60-pdrs., 8-in. and 9·2-in. by the end of 1916.[4] It was also thought possible that there might be 252 6-in. howitzers instead of 198 by the end of March, but it was not thought safe to base any calculations on the larger number.[5]

[1] The figures from July onwards are estimated deliveries (cumulative).
[2] A.2/1180 in D.M.R.S. 50.
[3] Major-General Du Cane came home as suggested, and was appointed head of the Design Department when design was transferred to the Ministry.
[4] D.M.R.S. 68, 87. The Master-General of the Ordnance was asked to send a new statement of requirements for gun ammunition to correspond with the modified estimates of gun deliveries. [5] C.R. 1329, D.M.R.S. 87.

TABLE "A."

(Enclosed in Sir John French's letter of 8 July, 1915).

Suggested Increase of Guns based on a Rate of Reinforcement of 5 Divisions every 2 months up to the end of October, and after that 3 Divisions a month, giving a Total of 50 Divisions by the end of April, 1916.

Gun	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	
13-pdr. ..	108	118	128	138	148	154	160	166	172	178	184	Horse Artillery remains stationary, 1 Section A.A. guns per Division.
18-pdr. ..	793	910	1,030	1,150	1,270	1,450	1,630	1,810	1,990	2,170	2,350	48 18-pdrs. per Division, part of the increase due to the gradual replacement of 15-pdr. B.L.C.
15-pdr. B.L.C.	204	204	204	204	204	168	132	96	60	24	0	
4·5-in. Howitzer	164	204	244	284	324	372	420	468	516	564	612	Existing establishments.
5-in. Howitzer	48	48	48	48	48	48	48	48	48	48	48	Do. do.
4·7-in. Q.F. ..	88	76	64	52	40	28	16	4	0	0	0	Gradually eliminated and replaced by 60-pdrs.
60-pdr. ..	36	58	80	102	122	166	226	274	320	360	400	One Battery per Division till October, after that 2 Batteries per Division. Remainder of increase to replace 4·7-in.
6-in. Howitzer	40	62	84	106	128	176	220	265	315	360	400	1 Battery per Division till October, after that 2 Batteries per Division.
6-in. B.L.C. ..	8	8	8	8	8	8	8	8	8	8	8	No increase.[1]
8-in. Howitzer	6	16	24	32	44	56	68	80	92	114	124	1 Battery per Corps till October, after that 2 Batteries per Corps.[2]
9·2-in. Howitzer	14	20	28	36	44	56	68	80	92	114	124	Do. Do.
12-in. Howitzer	0	4	4	8	12	16	20	24	28	28	32	Gradual increase up to total of 32.
15-in. Howitzer	3	3	4	4	4	4	4	4	8	8	8	Increase to 2 Batteries.
Total ..	1,512	1,731	1,950	2,172	2,396	2,702	3,020	3,327	3,649	3,976	4,290	

[1] We might have an increase of 6-in. Mark VII if a mounting could be extemporised.

[2] We do not know how many 6-in. B.L.C. guns are available for conversion to 8-in. Howitzers.

GUN PROGRAMME "B." (July, 1915).[1]

Type of Gun	Stock on 30 June	Estimated Deliveries (Cumulative).																		Total with date of completion
		July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
18-pdr. ..	1,700	240	500	780	1,080	1,400	1,720	2,040	2,360	2,680	3,000	3,320	3,407	3,407	3,407	3,407	3,407	3,407	3,407	6,107 (30/6/16).
4·5-in. ..	334	52	102	157	237	306	375	480	570	667	767	867	967	1,077	1,187	1,284	1,284	1,284	1,284	1,618 (30/9/16).
60-pdr. ..	67	11	26	49	77	105	139	183	227	271	331	391	451	531	611	691	733	733	733	800 (31/10/16).
6-in. How...	86	1	4	8	12	20	32	52	78	112	166	221	276	340	408	474	474	474	474	560 (30/9/16).
8-in. How...	24	—	—	2	5	8	13	18	23	28	38	48	48	48	48	48	48	48	48	72 (31/5/16).
9·2-in. ..	18	4	8	12	16	20	24	31	40	50	62	76	94	112	134	156	188	220	252	270 (31/12/16) —30 outstanding
12-in. ..	1	5	10	16	22	28	32	37	42	47	47	47	47	47	47	47	47	47	47	48 (30/3/16).

[1] D.M.R.S. 68.

III. Gun Programme "C.1."

One of the points in which Sir John French's letter differed from the War Office demand was with regard to 8-in. and 9·2-in. howitzers. Sir John French had asked for 8-in. and 9·2-in. howitzers in equal numbers, but the War Office statement bracketed the two together, showing apparently that the War Office would be content to receive either. From the supply point of view this was a very important matter. The Ministry was under the impression that no drawings or specifications for the 8-in. howitzer were in existence and it was assumed that it could only be obtained by converting 6-in. naval guns. The new programme called for 300 8-in. and 9·2-in. howitzers, and the proposal upon which the supply department was working was for the supply of 9·2-in. howitzers entirely, with the exception of some 48 8-in. howitzers which were to be converted from 6-in. naval guns by the Ordnance Factories. Messrs. Vickers were to supply 120 9·2-in. howitzers and Messrs. Beardmore 36, and on 4 August Mr. Lloyd George stated that he wished negotiations to be begun at once with the Bethlehem Steel Company for the purchase of 200 howitzers of the same type.

On the following day the Bethlehem Company's representative cabled to his firm :

> "Lloyd George wants you to do a semi-miracle for him and supply 200 9·2-in. howitzers at the rate of one a day from 1 February, 1916."

The firm promised (6 August) "to undertake anything that is humanly possible," their representative replying that "in these times our friends expect from you the superhumanly possible."[1]

It appeared, however, that the 8-in. was much simpler to manufacture than the 9·2-in., and Mr. West stated that the output of 8-in. shell would be 25 per cent. more rapid than that of 9·2-in.[2] If, therefore, Sir John French really regarded it as a matter of indifference whether 8-in. or 9·2-in. were supplied, all energies ought to be concentrated on the supply of the simpler weapon.

On 5 August, General Philipps, one of the Parliamentary Secretaries of the Ministry, asked the Master-General of the Ordnance for a definite ruling on the point.[3] The designs for the 8-in. carriage and the cradle were ready, and apparently there was no difficulty in making a design for the gun. The question of mobility was of such vital importance that it should not be too readily concluded that the 9·2-in. howitzer would be as acceptable to the Army as an 8-in. howitzer. In reply the Master-General of the Ordnance said that if it would accelerate delivery he would be prepared to accept half and half of 8-in. and 9·2-in. Investigations made by the Ministry confirmed the suggestion that the 8-in. howitzer could be manufactured more rapidly than the 9·2-in., as the design was much simpler. Messrs. Armstrong, for instance, anticipated no difficulty in delivering 40 howitzers of the 8-in. type by 30 June, 1916, in lieu of 12 of the 9·2-in. type, provided the new designs for the 8-in. (of which the War Office promised drawings in a few days) presented no

[1] C.R. 4423. [2] C.R. 4419. [3] D.M.R.S. 190A.

greater difficulty than the existing design. In the same way Messrs. Beardmore were prepared to deliver 14 8-in. guns instead of 10 9·2-in. by 31 March, 1916, and to deliver 16 8-in. per month afterwards instead of eight 9·2-in.[1] The Gun Department also suggested (10 August) that the proposed order from Bethlehem should be for 200 8-in. instead of 200 9·2-in. guns, which would probably secure better deliveries.[2] General Headquarters stated (15 August) that if 8-in. howitzers could be made more quickly than 9·2-in. they would be satisfied to receive them in the proportion of 100 8-in. to 60 9·2-in. It was presumably easier to make an 8-in. shell than a 9·2-in. and the extra mobility of the 8-in. howitzer must be set against the greater shell power of the 9·2-in. Everything, therefore, pointed to the advantage of supplying a greater number of 8-in. than 9·2-in.[3]

The new (Vickers) design of 8-in. howitzer (on similar lines to their 6-in. model), which was tried about 20 August, proved very successful, and the gun programme was therefore modified to provide a larger proportion of this type of gun.

Other discrepancies between the War Office demand and Sir John French's second letter needed clearing up.

According to Sir John French the replacement of 15-pdrs. by 18-pdrs. was to be postponed. It was to begin in November, 1915, but was not to be complete until April, 1916, instead of December, 1915. The 5-in. howitzer was not to be withdrawn, but no new guns of this type were to be made, and the 4·7-in. gun was to be replaced by 60-pdrs., and was to disappear in January, 1916.

These variations were of considerable importance from the point of view of the Ministry, especially with regard to the 4·7-in. gun. The statement from the Master-General of the Ordnance had implied that it was proposed to renovate the 4·7-in. gun, and as it was quite impossible for enough 60-pdrs. to be supplied to meet even Sir John French's requirements, based on 50 divisions, it was desirable for the Ministry to find out definitely whether the 4·7-in. gun was to remain in the field.

On 28 August the Army Council was informed that, "in accordance with a definite programme which had been the subject of informal communication with the War Office," the following orders had been placed by the Ministry:[4]

18-*pdrs.* :—582 guns, carriages (including rocking bar sights and dial sight carriers), and carriage limbers.

60-*pdrs.* :[5]—580 guns, carriages (with the exception of No. 7 dial sight and sighting telescope), and carriage limbers; 1,740 wagons and wagon limbers.

4·5-*in. Howitzers* :[6]—637 howitzers, carriages (including rocking bar sights and dial sight carriers), and carriage limbers; 1,911 ammunition wagons and ammunition wagon limbers.

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[1] D.M.R.S. 190A. [2] C.R. 4419. [3] D.M.R.S. 190A. [4] D.M.R.S. 179.

[5] 180 of these complete equipments had been ordered from the Royal Ordnance Factories.

[6] 176 of these had been ordered from the Royal Ordnance Factories.

6-in. Howitzers :—458 howitzers, carriages (including sights, but not No. 7 dial sight and sighting telescope), and carriage limbers.

8-in. Howitzers (Vickers type) to be ordered :—132 howitzers, carriages (including sights, but not No. 7 dial sight and sighting telescope), and carriage limbers.

9·2-in. Howitzers :[1]—120 howitzers, and howitzer mountings (not including No. 7 dial sight and sighting telescope).

12-in. Howitzers :[2]—16 howitzers and mountings (not including No. 7 dial sight and sighting telescope).

On 1 September the War Office stated that these orders covered their present requirements. The gun programme, therefore, was regarded as settled on the 70-division basis. Guns and equipments had been ordered from the armament firms up to the limit of their capacity, and the Ministry was giving what help was possible in the way of supplying labour, machine tools, and raw material. It was hoped that these arrangements would place 1,792 heavy guns at the disposal of the Army, viz. :—

60-pdr.	800
6-in. Howitzer	560
8-in. / 9·2-in.	372
12-in / 15-in.	60

For this additional amount of heavy artillery in the field increased personnel was naturally required, and the War Office made provision for 1,896 officers and 43,130 other ranks, besides a large number of motor transport drivers.

By this time, however, Mr. Lloyd George had taken action which resulted in the adoption of a largely increased programme for heavy guns (known in the Ministry as Gun Programme C.1.). The events of August — the Russian retreat and the failure of the Suvla Bay attack in the Dardanelles—showed that 1916 would be a critical year for the Allies. Mr. Lloyd George thought that Great Britain ought to put 100 Divisions into the field,[3] and determined that if the Government came to the same decision, guns and other equipment should not be lacking.

The first considerable bombardment with heavy guns that the British Army had been able to undertake had been at Hooge, when for ten days, from 1 August to 9 August, the German lines had been shelled by 9·2-in and 8-in. howitzers as a preliminary to an attack. The effect had been extraordinary. Ground lost had been regained with comparatively few casualties, and the bombardment had put new heart into the troops.

[1] The order for thirty-six 9·2-in. equipments originally placed with Messrs. Beardmore had been changed to 8-in. equipments.

[2] Messrs. Armstrong had been instructed to complete only eight of these on railway mountings, the remaining eight to be ordered when the type was finally settled.

[3] *See* Vol. II, Part I, Chap. II.

> "They felt that conditions were changing since the second battle of Ypres, when we had been powerless to reply to the German guns. Now at last we seemed to be on an equality. The best tonic for overwrought nerves and sinking spirits was the sound of our great shells screaming overhead, and the sight of mushrooms of dust over the enemy's line."[1]

The success of this sustained bombardment strengthened Mr. Lloyd George's conviction that one of the chief needs of the Army for the proposed offensive in the spring was an ample provision of heavy artillery, and on 24 August he took steps to find out whether it was possible to increase the output of heavy guns and howitzers at home or in Canada or the United States.

Mr. Ellis, Deputy Director-General (D) in the Department of Munitions Supply, who was responsible for the supply of guns,[2] reported on 24 August that there was a prospect of some increase over the estimates in the output of 60-pdrs., while the adoption of 8-in. howitzers in place of 9·2-in. howitzers would considerably increase deliveries from Messrs. Armstrong and Messrs. Beardmore in the spring. He felt doubtful, however, if the placing of further orders would increase the output.

> "Every possible use of sub-contractors is being made; the ordnance firms are notified daily of any information which reaches me of firms who can undertake work which will tend to assist or accelerate delivery.
>
> "In my judgment, this, and the supervision of supply of machinery and assistance as to labour—all of which have been brought prominently before the contractors—are the only ways of giving assistance. I do not consider that any financial assistance or the placing of larger orders would enable the contractors to do any more than they are doing.
>
> "Machinery makers are fully occupied by existing orders until January to March of next year. American deliveries are in a similar condition. I will make inquiries as to possible deliveries after the conclusion of existing machinery orders, and as to further sources of supply. At present the ordnance contractors have confined themselves to the necessary machinery to enable them to carry out their promises of delivery of the guns and equipments for the new programme."[3]

His report did not hold out any prospects of a great increase in supplies from America. Four hundred 18-pdr. equipments had been ordered from the Bethlehem Steel Company, and enquiries were being made as to the rate at which they could deliver 8-in or 9·2-in. guns. He agreed with Mr. D. A. Thomas (later Lord Rhondda) that the Bethlehem Steel Company and the Midvale Steel Company—the latter of which was under German influence and at that time declined to manufacture for the Allies—were the only firms capable of making big guns and howitzers. Some anti-aircraft guns might possibly be obtained from Canada, but there was no machinery there suitable for big gun manufacture.

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[1] Buchan, *History of the War*, ix, 107. [2] *See* below p. 57. [3] C.R. 4419.

Mr. Lloyd George felt that more might be done.

"I cannot help thinking," he wrote (25 August), "that the capacity of the United States of America for turning out big guns has been considerably under-estimated. Should the United States of America be forced into the conflict, I have no doubt that their Government would find means to manufacture a prodigious number of guns of all calibres in their own country. This enquiry must be pressed further."

On the following day (26 August) Mr. Lloyd George made a momentous decision—that the existing gun programme, which was designed for an Army of 70 Divisions, must be expanded to provide for an Army of 100 Divisions, and that additional artillery must be ordered to provide a margin varying from 10 per cent. to 25 per cent. on the programme for each type of gun. Further, Mr. Lloyd George was prepared to place orders for still more guns provided the larger orders would stimulate contractors to lay down more plant and give an increased output in the first half of 1916.

General Philipps in a minute to Sir Frederick Black, Director-General of Munitions Supplies, on 27 August, defined the position as understood by him on that date in the following tables.

REQUIREMENTS FOR 100 DIVISIONS.

33 Army Corps (32 of 3 Divisions and 1 of 4 Divisions).
11 Armies (10 of 9 Divisions and 1 of 10 Divisions).

Field Anti-Aircraft Guns, 2 per Division = 200 (plus 25 per cent. = 50)* ..		250
18-pdr., 48 per Division = 4,800 (plus 25 per cent. = 1,200)		6,000
4·5-in. Howitzers, 16 per Division = 1,600 (plus 20 per cent. = 320) ..		1,920
60-pdr., 8 per Division = 800 (plus 15 per cent. = 120)		920
6-in. Howitzers, 8 per Division = 800 (plus 10 per cent. = 80)		880
8-in. Howitzers 9·2-in. Howitzers	16 per 3 Divisions = 528 (plus 10 per cent. = 52) .. (33 Army Corps).	580
12-in. Howitzers 15-in. Howitzers	8 per 9 Divisions = 88 (plus 10 per cent. = 9) .. .. (11 Armies).	97
	Total	10,647

	Total Guns required as above for 100 Divisions	Existing from before War.	Guns under order or delivered.	Balance required to complete for 100 Divisions. and spares.
A.A. Field Guns ..	250	(114)**	Nil.	250
18-pdr.	6,000	897	4,210	893
4·5-in. Howitzers ..	1,920	169	1,449	302
60-pdr.	920	31	769	120
6-in. Howitzers ..	880	86	474	320
8-in. Howitzers 9·2-in. Howitzers	580	1	371	208
12-in. Howitzers 15-in. Howitzers	97	Nil.	60	37
Total	10,647	1,184	7,333	2,130

* These margins were added to provide for wastage and repair (D.M.R.S. 229).
** 13-pdr. H.A. gun.

Mr. Ellis had already been considering what orders could be placed to meet this enormous programme, and by 27 August he had communicated with all the British gun-making firms and was ready to place further orders as soon as he obtained the Ministry's sanction. He pointed out that the usual course of procedure appeared to be for the Ministry to receive requisitions from the War Office, and asked General Philipps to arrange for this if this method was to be adopted. As will be seen below, however, this was an anomalous programme in which Mr. Lloyd George took the initiative on his own responsibility, without consulting the War Office.

On 26 August, Mr. Ellis explained the delay in placing orders for heavy guns with the Bethlehem Steel Company. The company had telegraphed on 21 August saying that they could not deliver any 9·2-in. howitzers until seven months after they had received the working drawings, but since that date the simpler design of 8-in. gun had been settled, and the firm had been urged by telegram to supply these guns at a much earlier date. Their agent in London was convinced that they could do this, and if they could promise satisfactory deliveries they would be given an order for 200 howitzers of this type.

On the same day (26 August) information was received that the Midvale Steel Company had been reconstructed and freed of German influence and was prepared to work for the Allies.[1] This opened up a new source of supply, and on 27 August Mr. Thomas was asked by cable to enquire into the gun-making capacity of this and other American firms. The last paragraph of the cable is extremely significant :—

> "We are prepared to give contract for programme over period two years or more if by so doing we can ensure large deliveries within first half of 1916."

Some account of the negotiations with the American gun-making firms and the allocation of the orders is given below,[2] but in order to trace the evolution of the gun programme it is important to notice that by 30 August Mr. Ellis was in a position to meet the programme, and had prepared a provisional allocation of orders involving an expenditure of about £12,150,000, of which £7,753,000 would be on overseas orders.[3]

General Philipps submitted his proposals to the Minister on 31 August with the statement that the figures given by Mr. Ellis were in proportion to the existing accepted standard per Division for 100 Divisions, with 100 6-in. howitzers, 100 8-in. howitzers, and 110 9·2-in. howitzers in excess of that standard.

Mr. Lloyd George sanctioned the proposal on the same day, as follows :—[4]

> "Guns to be ordered as in Mr. Ellis's note dated 30 August for 100 Divisions with *excess* as stated in General Philipps' note above, viz :—

6-in. Howitzers	100
8-in. Howitzers	100
9·2-in. Howitzers	110

> with the addition of a further 50 9·2-in. Howitzers.

[1] *See* below, Chap. V. [2] Chap. V. [3] C.R. 4423. [4] D.M.R.S. 190.

"Ammunition to be ordered in United States of America according to scale for guns ordered in United States of America —and 33 per cent. surplus for guns ordered at home—all the rest from home."

General Philipps communicated the Minister's order to Sir Frederick Black, Mr. Ellis and Mr. West (who was responsible for the supply of shell), with instructions that the additional 50 9·2-in. howitzers were to be ordered in America (31 August). A revised table of gun ammunition requirements was to be prepared distinguishing between orders to be placed at home and abroad.

At this moment serious financial difficulties threatened the American part of the new programme. On 31 August, the Treasury warned the Ministry that cash payments on new contracts in the United States of America and Canada must be kept down to a minimum in October and November. The proposed additional orders for guns and shell were discussed with the Treasury from this point of view, early in September, and the Ministry agreed to avoid, if possible, making any cash payments during the next few weeks.

As a matter of fact, the orders for 4·5-in. howitzers and 9·2-in. howitzers were not placed with the Bethlehem Steel Company until 1 October and 15 November, while the Midvale negotiations dragged on until April, 1916. The period of the greatest financial stringency, therefore, was over before payments upon these contracts became due.[1]

IV. Negotiations with the War Office.

Mr. Lloyd George had thus, on his own responsibility, ordered a large number of heavy guns, additional to those asked for by the War Office. By 8 September it appeared that the War Office had also come to the conclusion that Gun Programme "B." was insufficient.[2] The Army Council enquired whether the Ministry of Munitions saw any prospect of obtaining deliveries of 6-in., 8-in., 9·2-in. and 12-in. howitzers, together with the correct amount of ammunition, either at earlier dates or in larger numbers than the deliveries notified by the Ministry on 30 July, 1915, as, should it be possible to do so, and the dates of delivery were satisfactory, the Army Council would be prepared to consider an increase in the numbers to the extent shown below :—

	Present Order.	Additional.	Total.
6-in. Howitzers	458	160	518
8-in. } 9·2-in. } Howitzers	252	112	364
12-in. Howitzers	16	16	32

None of these fresh orders were to be placed at the expense of any other equipment without reference to the War Office.

[1] 94/G/722 ; Hist. Rec./H/1141/6. [2] 57/3/4905 ; D.M.R.S. 190.

The War Office thus asked for an addition of 288 guns to the existing programme. Mr. Lloyd George's programme, of course, went far beyond that, and on 14 September, the Ministry explained the situation and stated that orders had already been placed which would not only cover the additional numbers suggested by the Army Council in their letter of 8 September, but would also provide a very considerable margin for possible future needs.[1]

The following table showed the position :—

GUN PROGRAMME "C."

TYPE.	Guns ordered and to be ordered in addition to those in existence on 1 July, 1915.	Maximum number of Guns for which it is proposed that Ammunition should be provided.
Anti-Aircraft 3-in. Gun	200	200
Anti-Aircraft Field 18-pdr. throwing 13-pdr. Shell	250	200
18-pdr.	4,300	4,800
4·5-in. Howitzer	1,586	1,600
60-pdr.	852	800
6-in. Howitzer	894	900
8-in. Howitzer	439	430
9·2-in. Howitzer	359	358
12-in. Howitzer	84	76

The reasons for the action taken were explained as follows :—

" The Minister has been influenced in providing such a margin by the important consideration that the ordering of these large quantities will make it worth while to have new machinery on a larger scale installed, both at home and abroad, which will hasten the dates at which considerable deliveries can take place in 1916. A larger number of heavy guns will by this plan be delivered during the critical first months of 1916 than would otherwise have been possible."

Information as to the precise numbers and dates of delivery would be forwarded as soon as the details could be worked out, but, in the meantime, the maxima to which the Ministry proposed to work were shown in a statement attached.

On 15 September the War Office asked for a statement showing what improvement in deliveries would result from the new orders.[2] The estimates of the probable deliveries of guns, month by month, referred to by the Ministry followed in due course (21 September).[3]

The number of guns in these estimates were smaller in some cases than the numbers given in the 14 September statement, owing to the fact that some of the guns would not be completed until after

[1] D.M.R.S. 190.
[2] 57/3/5905 in D.M.R.S. 190.
[3] D.M.R.S. 190. This statement was based upon tables drawn up by Mr. Ellis showing each maker's estimates of his monthly deliveries of guns. (C.R. 4419.)

September, 1916. The estimated rate of deliveries of 18-pdrs. was noticeably slower, owing to the fact that a number of 4·5-in. guns had been ordered from the Bethlehem Steel Company, which would retard the execution of their 18-pdr. contract. The statement showed that deliveries of 6,839 guns were anticipated by the end of September, 1916, rising to 7,103 by December, 1916.

This estimate of deliveries, which was known as Gun Programme "C," is printed below.

DEPARTMENTAL ESTIMATE OF PROBABLE DELIVERIES.[1]

1915.	18-pdr.[2]	60-pdr.	4·5-in. How.	6-in. How.	8-in. How.[3]	9·2-in. How.	12-in. How.[4]
July ..	235	8	42	—	—	2	4
August ..	290	5	43	2	—	4	—[6]
September ..	334	16	52	8	2	4	5
October ..	363	24	75	6	3	4	7
November ..	370	28	75	9	3	4	7
December ..	370	36	88	16	111	6	6
1916.							
January ..	370	43	111	37	12	8	5
February ..	370	50	96	58	21	10	5
March ..	251	52	108	63	31	15	—
April ..	64	68	127	70	29	16	—
May	70	81	140	70	29	21	—
June ..	20	81	160	85	29	30	—
July ..	80	87	170	85	29	39	—
August ..	80	87	170	90	27	45	—
September ..	100	87	127	70	13	45	—
	3,307	753	1,584	664	239	253	39
October ..	100	87	—	30	—	34	—
November ..	—	13	—	—	—	—	—
Total ..	3,407	853	1,584	694	239	287[5]	39

The cost of the extension of the gun programme was estimated at £10,000,000, taking the cost of the old programme at between £22,000,000 and £23,000,000 and the cost of the new programme at between £32,000,000 and £33,000,000, but it was pointed out that in most of the cases the prices of guns had not been fixed, and that it was by no means clear that the programme would be carried out at the existing prices.[7]

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[1] No account is taken in this table of any possible deliveries from Midvale.

[2] 161 of these guns may be required for A.A. Guns ; in such case this column will require revision.

[3] Including 48 converted from 6-in. to 8-in.

[4] Further 12-in. Howitzers will be ordered as soon as type is settled.

[5] Leaving 73 for Bethlehem subsequent to October.

[6] One gun delivered in August was accidentally omitted from this statement. It brought the total to 40 12-in. howitzers.

[7] Minute by Mr. Layton to the Minister, 8 October, 1915. (D.M.R.S. 229.)

It is interesting to show how these orders for guns were distributed :

Type.	Armstrong	Vickers	Coventry Ordnance Works	Beardmore	Ordnance Factories	Bethlehem	Total
18-pdr.	1,156	1,212	—	359	30	550	3,307
60-pdr.	597	36	—	—	220	—	853[1]
4·5-in.	—	—	1,176	—	258	150	1,584
6-in. Howitzer ..	—	484	—	180	—	—	664
8-in. Howitzer ..	98	1	—	92	48	—	239
9·2-in. Howitzer ..	—	191	—	—	—	62[2]	253
12-in. Howitzer[3] ..	32	8	—	—	—	—	40

Negotiations with the Midvale Company were in progress for 200 6-in. and 200 8-in. howitzers, and orders for 980 18-pdr. field guns were being temporarily reserved to see if Canada could take up gun manufacture.[4]

At this date the designs for the 6-in. and 8-in. howitzers were still not finally settled, but working drawings of them were despatched by Messrs. Vickers to the contractors before 6 October, and the Army Council stated that sealed drawings and specifications would follow later.[5] The 12-in. howitzers ordered under Programmes " A " and " B " were to be of the rail type, which would be suitable for use in any country where the railway gauge was the same as in England.

In view of the unorthodox character of the programme, Mr. Ellis asked for and obtained the Minister's authority to order the same supply of spare parts as would have been ordered if demand notes had been received from the War Office (30 October, 2 November), but as there was an existing and prospective surplus of wagons and wagon limbers, Mr. Ellis omitted them (wherever possible), for the time being, from the orders he was placing.[6]

The Ministry's letter of 14 September was the first intimation that the War Office had that a large additional programme had been adopted ; while the table which accompanied the letter of 21 September showed that the Ministry proposed to supply 1,035 guns over and above those required for the 70 divisions for which the War Office had been legislating.

In order to place these guns in the field, an increased personnel of 4,980 officers and 119,198 other ranks would be required, which with the increased personnel already provided, meant a total addition to the Army of 6,876 officers and 162,328 other ranks. Lord Kitchener thought it would be impossible to find this increased number of gunners. He thereupon consulted Sir John French and his staff as to the requirements of the Army in the Field, in order to find out whether the Ministry had adopted this large programme as a result of the Boulogne Conference, as, though General Du Cane of the Headquarters Staff had been present at the Boulogne meeting, the conclusions then arrived at had not been communicated to the War Office.

[1] This is 100 more than the figure given in Programme C, and is taken from Mr. Ellis's table of anticipated deliveries.

[2] The firm to deliver 88 more at the rate of 15 per month after September.

[3] Forty more of these guns were to be ordered. (Note by Mr. Ellis, 22 September.)

[4] Minute by Mr. Ellis, 30 October. (D.M.R.S. 214).

[5] 57/3/4905 in D.M.R.S. 214.

[6] D.M.R.S. 214.

Sir John French informed Lord Kitchener officially that the request he put forward in his letter of 25 June,[1] on which the War Office requirements were based, was arrived at " a week after the conference at Bolougne, after due consideration of the opinions there expressed, and that it still represented his requirements."[2]

On 27 September, the Ministry reported that it had not been able to place orders to meet the whole of its programme, the orders placed falling short of the programme by 200 6-in. howitzers and 200 8-in. or 9·2-in. howitzers. Four 12-in. howitzers had, however, been ordered in addition. Even so, the orders already given entailed a considerable surplus over the requirements of the War Office, as appears from the following table.[3]

Type.	A. Number of guns delivered from outbreak of War to 30 June, 1915.	B. Number of guns additional to A under Gun Programme B.	C. Number of guns additional to A under New Gun Programme.
18-pdr.	803	3,407	4,300
13-pdr.	Nil.	242	242
3-in. Anti-Aircraft Guns	Nil.	Nil.	200
18/13-pdr. Anti-Aircraft Guns..	Nil.	Nil.	250
4·5-in. Howitzer ..	165	1,284	1,586
60-pdr.	37	732	852
6-in. Howitzer ..	Nil.	474	894
8-in. Howitzer ..	24*	48*	439†
9·2-in. Howitzer ..	17	282	359
12-in. Howitzer ..	1	47	84

* Conversion of 6-in. naval guns.

† Forty-eight of these will be conversions of 6-in. naval guns.

Lord Kitchener estimated the surplus in terms of Divisions as follows :—

60-pdr. ..	120	guns equivalent to	15 Divisions.
6-in. How. ..	220	,, ,,	27 ,,
8-in. How. / 9·2-in. How.	259	,, ,,	49 ,,
12-in. How. / 15-in. How.	40	,, ,,	45 ,,

On 1 October, 1915, therefore, the Army Council wrote to the Ministry, suggesting the transference to Russia of some of these additional orders for heavy howitzers.[4] With the exception of a reserve of 80 6-in. howitzers, 54 8-in. or 9·2-in. howitzers and 8 12-in. or 15-in. howitzers, they considered that the requirements of the Army would be fully met by the orders notified to them on 28 August.[5]

[1] *See* above, p. 6.
[2] 57/3/4905 in D.M.R.S. 214.
[3] D.M.R.S. 179, 214.
[4] 57/3/4905 in D.M.R.S. 214.
[5] *See* above, p. 15.

Mr. Lloyd George was not prepared to cancel any of his orders for heavy howitzers. An Allied offensive on 25 September, following a bombardment of the enemy's positions lasting 25 days, had won considerable successes, and the British advance at Loos was due in no small measure to effective artillery work. The prospects of the spring offensive appeared to depend upon an unlimited supply of heavy artillery, and on 2 October, the Ministry wrote to the War Office as follows :—[1]

> "Apart from the question of whether the total number of guns ordered, when ultimately delivered, will be in excess of British requirements, the Minister is of opinion that the placing of these large orders now will have the effect of expediting deliveries,[2] and that they are necessary in order to ensure the delivery during the spring and summer of 1916 of a substantial part of even the War Office requirements. I am to add that it is Mr. Lloyd George's view that the early delivery of the extra guns might very well have a decisive effect on the campaign. He is advised that even with this large order the War Office requirements will probably not be fully attained until September, 1916.
>
> Should the Secretary of State differ from the above views, the Minister of Munitions is prepared at any time to discuss the matter with him, or if he should prefer, he might bring it before the attention of the Cabinet. The Minister is not, in any case, prepared to cancel the orders he has placed for the provision of heavy howitzers, unless the Government as a whole will take the responsibility of deciding that the proposed provision is excessive.
>
> "Should it ultimately appear that the provision of guns and ammunition secured by the additional orders is unnecessary for British requirements, the Minister considers that it would still be possible to make any surplus available for the Allies."

The War Office was unable to accept Mr. Lloyd George's argument, which did not meet the main difficulty—that of providing the personnel for the additional batteries. Even if the men were forthcoming, Lord Kitchener stated that it would be quite impossible to find the artillery officers necessary to put the guns into the field. He strongly urged that the extra guns should be provided for Russia, where personnel could easily be provided to use the guns against the enemy, and that the additional 60-pdrs., 6-in., 8-in. and 12-in. howitzers should be manufactured of a calibre or pattern to take Russian ammunition of the type used by the equivalent heavy guns in the Russian Army, and thus avoid the confusion and difficulties caused by different ammunition in the field, to which the Russian military authorities greatly objected.

The question was discussed at the Four Power Conference in November.[3] Russia had asked for 1,000 field howitzers (4·5-in.) and a large number of heavy guns and howitzers, and the War Office

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[1] D.M.R.S. 214.

[2] Mr. Ellis had drawn attention to the improvement in deliveries that were obtained as a result of placing large orders for one type of ordnance. 2 October, 5 October, D.M.R.S. 190.

[3] For an account of this, *see* Vol. II, Part VIII, Chap. I.

had written to General Hermonius stating that from April, 1916, onwards they expected to be able to spare one-sixth of the current deliveries of guns—say, 20 4·5-in., 10 6-in., 5 9·2-in., 4 12-in., and possibly some 15-in. guns—but the French were particularly anxious that Great Britain should not transfer any of the heavy pieces that had been intended for her Armies on the Western front. It was obvious that Russia would not have to attack an elaborately fortified system like that on the Western front, and that a large number of field howitzers would be more useful to her than a small number of heavier guns. Great Britain, therefore, promised to supply Russia with 300 4·5-in. howitzers, to be delivered in February, March and April.[1] The War Cabinet sanctioned this proposed allocation after some discussion, as it was supported by Mr. Asquith and Lord Kitchener as well as Mr. Lloyd George.

Mr. Lloyd George later proposed that an option for the manufacture of 200 6-in. and 200 8-in. howitzers by the Midvale Company should be transferred to Russia, and on 3 December it was decided that as the British Government no longer required guns from Midvale on its own account the option should be transferred to Russia, a contract for 100 8-in. howitzers being placed on 4 April, 1916.[2]

The general question of Mr. Lloyd George's additional programme was placed before the Cabinet Committee on the Co-ordination of Military and Financial Effort, and after considering the matter in detail the committee were satisfied that the orders placed by the Ministry in excess of War Office requirements were necessary in order to secure a very large output in the early part of 1916.

The War Office made another attempt to reduce the orders for guns, howitzers and ammunition (5 January), but in view of the decision of the Cabinet Committee the Minister refused to re-open the question.[3]

V. The Programme of December, 1915—the 6-in. Howitzers.

The fighting round Loos in September and October had proved that the 6-in. howitzer was a specially valuable weapon.

On 28 November Sir John French wrote to the War Office as follows :—

> "I am more than ever convinced of the value of this particular type of weapon for employment in the present campaign. In the majority of the sectors lighter shell have not sufficient power to make the bombardment effectual, while the heavier, especially when the opposing lines are in close proximity, must needs be devoted to objects of importance further in the rear."[4]

He pointed out that the supply of 6-in. howitzer batteries with the Army in France was far below the standard he had set in his letter of 25 June. He had asked that the number of 6-in. howitzer batteries

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[1] It was decided that Messrs. Vickers, who had been making 8-in. and 12-in. howitzers for Russia, should not be allowed to take a continuation order as Russia had accepted the 300 4·5-in. howitzers in lieu of heavy guns. 0149/3230 in D.M.R.S. 190.

[2] *See* below, p. 65. [3] 14 February, 1916. (D.M.R.S. 214.) [4] D.M.R.S. 190.

should be raised to one per Division and that this proportion should be doubled during the winter so that there might be two batteries per Division by the spring of 1916 (or 560 guns on the 70-Division basis). There were only 18 6-in. howitzer batteries then in France, and of these 13 howitzers were nearly worn out and would shortly require replacement, so that Sir John French could count on barely 15 batteries, and he urged that special efforts should be made to supply this deficiency.

In reply to urgent requests for revised forecasts of deliveries of this howitzer a provisional estimate was forwarded by the Ministry on 9 December. This showed a considerable decrease on the September forecast—170 in lieu of 193; but an estimate sent two days later after further investigations was still more disappointing. It now appeared that not more than 67 6-in. howitzers would be delivered by 31 March, though 602 were expected by the end of September.[1]

The decrease was primarily due to Messrs. Vickers, who on 11 December informed the Ministry that the figure of 150 howitzers given by them must be taken as referring to guns only, " as subsequent enquiries from their sub-contractors in carriage work pointed to considerable delay in the delivery of the various parts which made up the whole."

On 13 December, the Army Council informed Sir John French that 67 6-in. howitzers would be delivered by 31 March.[2] The Army Council was unable at the moment to state how many of these howitzers would be required in other theatres of war, but every effort was to be made to supply the force under Sir John French's command with as many of this nature of howitzer as possible and at the earliest possible date.

On 23 December the Ministry forwarded its final estimate for the year of deliveries over the next nine months, which gave an interesting comparison with the September forecasts, showing that all the estimates had had to be revised in a downward direction. It was anticipated that 7,516 guns (without counting the twelve 15-in. howitzers) would be delivered by the end of September instead of 7,908. The shortage was most marked in the earlier months of the year and in the 6-in. and 8-in. types.[3]

The decline was due to scarcity of labour, Mr. Ellis reporting on 20 December that 750 machines were then standing idle for lack of men. He stated that the new estimates were as reliable as he could make them, but pointed out that they were dependent on the provision of men to man the new machinery and the supply of the necessary fitters and other workmen for hand work.. In addition there was no doubt that the deliveries of machine tools would be far behind anticipations, so that the considerable acceleration of output expected in the early months of 1916 would not be realised.[4]

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[1] This deficiency was aggravated by the fact that owing to the agreement with Russia there would be a shortage of 4·5-in. howitzers in February, March and April (D.M.R.S. 190).

[2] 121/Stores/4017 in D.M.R.S. 190. [3] C.R. 4419. [4] *Ibid.*

CHAPTER III.

THE LATER GUN PROGRAMMES, 1916–1918.

I. Further Orders for Heavy Howitzers.

As has been seen, the War Office on 5 January, 1916, put forward proposals for the reduction of the gun orders already placed by the Ministry, on the ground of economy, and because the casualties to guns were less than had been expected, but Mr. Lloyd George refused to modify these orders.[1] A few days later the War Office found it necessary in the case of the 18-pdr. to ask for an increase of 200 equipments, thus bringing the requirements to 3,407 equipments, including 90 guns on anti-aircraft mountings. On 24 March the Ministry was asked to hasten the supply of at least 200 of the equipments then due for delivery, and promised if possible to provide them by the end of April.[2]

The demand for heavy howitzers also grew rapidly. On 14 January the Ministry was asked to supply, by April and May, at least 89 6-in. and 44 8-in. howitzers beyond former requirements. The Admiralty was approached, and agreed to help by postponing some of the work on 13·5-in., 12-in., and 9·2-in. naval guns already in hand at the Ordnance Factories, and at Messrs. Vickers' and Messrs. Armstrong's works.

The German attack on Verdun in the spring of 1916, in which the enemy used mainly 8·2-in. and 9·4-in. howitzers, emphasised the value of weapons of this type. On 13 April Mr. Lloyd George wrote as follows : " This [news] supports and justifies the policy of the Ministry with regard to its heavy howitzer programme, and points to the desirability of increasing it still further."[3] The Minister therefore wished continuation orders for 8-in. and 9·2-in. howitzers to be given at once, and orders for delivery by 30 June, 1917, were allocated as follows (17 April) :—

Messrs. Armstrong	88 8-in.
Ordnance Factories	30 8-in.
Messrs. Vickers	175 9·2-in.

II. Heavy Artillery Establishments : Sir Douglas Haig's Letter of 24 June, 1916.[4]

An important landmark in the development of gun programmes was reached with a letter from the Commander-in-Chief (24 June), dealing with provision for the future and improvements in design.

Sir Douglas Haig pointed out that uniformity of establishment was of cardinal importance ; much labour, inconvenience and delay being caused when a great many different types and calibres were maintained in the field concurrently. But, while pressing for greater simplicity, G.H.Q. realised that this could not at once be attained, owing to complications in the manufacturing position.

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[1] D.M.R.S. 214. [2] D.M.R.S. 190.
[3] D.M.R.S. 190. The demand had been anticipated in January. (D.D.G.(D. 144/4.) [4] D.M.R.S. 404.

Sir Douglas Haig divided artillery into three main groups for the purposes of discussion :—(1) divisional artillery—mobile field artillery, moving with a Division ; (2) corps artillery—heavier, but still able to follow the movements of troops ; (3) army artillery—heaviest of all, requiring special arrangements for transit.

As regards the first group, no change was proposed. The establishment stood at 48 18-pdrs. and 16 4·5-in. howitzers for each Division.[1] For the third group, the plan was to eliminate by degrees all but two types—heavy howitzers tractor-drawn or on railway mountings, and guns of 9·2-in. or over on railway mountings. The proposed establishment for an Army comprised 16 howitzers, of which probably half were to be tractor-drawn, and four guns on railway mountings.

The second group, the corps artillery, formed the main subject of the letter, and it was here that far-reaching changes were proposed. This branch of the artillery was to have priority of construction over the other two. The aim was to have only two classes of gun—the 60-pdr. and the 6-in. ; and two classes of howitzer—the 6-in. and one of the 8-in. type, but with longer range.

Two scales of provision were submitted. Scale A shewed the strength which the Commander-in-Chief considered it essential to reach before the 1917 campaign began, and Scale B the strength which should be reached as soon as possible thereafter.

Corps Artillery.	*Scale A.*	*Scale B.*
60-pdr.	16	24
6-in. Howitzer	40	60
6-in. Gun	4	8
8-in. and 9·2-in. Howitzer	16	24
	76	116

Sir Douglas Haig explained the reasons for this great increase on the estimates made in the summer of 1915. " The importance of being able to develop a superiority of heavy artillery fire when and where required without having to resort to the laborious and often dangerous process of transferring large numbers of guns from other parts of the battle front cannot be over-rated." The Germans were working up to a scale of 84 heavy guns and howitzers per Corps of three Divisions.[2]

With regard to design, G.H.Q.'s main requirement was for increased range, the great importance of which was becoming more and more evident.[3] It was not possible, at the moment, for Sir Douglas Haig's wishes to be met without delaying production.

The War Office based its new programme on an establishment of 72 Divisions, 12 more than had been estimated for in Sir Douglas Haig's letter, and allowed for a reserve of 25 per cent.[4] Except in the case of 60-pdrs., orders for which had already been placed on a scale giving a surplus of 120 guns over Scale B, the War Office decided to aim at Scale A only for the moment (6 July),[5] and stated that the

[1] In a further letter of 30 June, Sir Douglas Haig said that the existing 18-pdr. must be maintained until it could be replaced by an equipment with longer range.

[2] The demand for anti-aircraft guns was also increased. See Vol. X, Part VI.

[3] *See* below, p. 49.

[4] 6 July, 1916 (D.M.R.S. 404).

[5] It was decided to allocate these 120 surplus guns to the Allies.

proposal to increase the establishment up to Scale B would be further considered in the light of more experience, when the Scale A programme was approaching completion.

Although the orders for 8-in. and 9·2-in. howitzers already placed also reached Scale B, Scale A was adopted for these weapons. The surplus was, however, to be kept in hand in order that it might be possible to adopt Scale B later on, and the War Office decided that these natures must not be allotted to the Allies beyond the ratio of one in three.

Thus the new programme was as follows :[1]—

GUN PROGRAMME OF JULY, 1916.

Requirements for New Programme and additional Guns for 12 extra Divisions (4 Corps); also Reserves for both.[2]

	12-in. How.	60-pdr.	6-in. How.	8-in. & 9·2-in.[3]	6-in. Gun.	13-pdr.	3-in. 20-cwt.
New Programme for France	80	480	800	320	80	160	100
Additional Guns for 12 Divisions ..	—	96	160	64	16	32	8
Reserve	8	144	240	96	24	48	10
	88	720	1,200	480	120	240	118
In hand or on War Office Order ..	56	800	720[4]	426	40	150	13
Ordered by Ministry of Munitions in addition	29	120	394	514	—	—	—
Total	85	920	1,114	940	40	150	13
Deficiency (to be ordered)	3	—	86	—	80	90	105

As the result of an Allied conference on 12 July, it was decided that more 6-in. guns were needed, and on 15 July[5] the War Office adopted Scale B for this gun. The new requirements were as follows :—

For 20 Corps at eight per Corps	160
For four extra Corps at same rate	32
25 per cent. reserve	48
Total ..	240

Of these, 180 were to be 6-in. 35 calibre equipments with 30 spare guns, and 60 were to be 6-in. Mark VII equipments with ten spare guns.

[1] D.M.R.S. 404. [2] 120 howitzers for Russia also to be ordered.

[3] G.H.Q. preferred the 8-in. howitzer to the 9·2-in., but the War Office decided that the two should be supplied concurrently as before. (D.M.R.S. 404.)

[4] Eighty additional to replace 30-cwt. howitzers.

[5] D.M.R.S. 404. On 9 July, G.H.Q. put forward an urgent secret demand for 25 6-in. guns, as ten had been put out of action since 1 June, and though these had been replaced the remaining 22 would probably be condemned soon for wear. (D.M.R.S./404. H.)

A week later (22 July) the War Office increased its demand.[1] It proposed to take 50 6-in. Mark VII guns from coast defence to make good wastage in the field, replacing them by 50 Mark VII guns from those available or already ordered—thus 50 more would have to be put in hand to keep up the present numbers. The Ministry of Munitions inquired whether the 50 extra 6-in. Mark VII guns to be ordered were intended only for coast defence; otherwise the manufacture of this old type was deprecated, since the Mark VII guns could not be made any more quickly than the new 35 calibre, and if intended for service in the field, it appeared undesirable to continue manufacturing an inferior weapon. The War Office explained that the guns were wanted for home defence and the Ministry placed orders accordingly, arranging that the Mark VII guns were not to have priority over the 35 calibre equipments.[2]

III. The Programme of September, 1916.

A letter of 23 September from Sir Douglas Haig formed the basis of a new programme.[3] G.H.Q. reported that the summer's experience had justified the policy set out in the letter of 24 June. It was now essential to bring the artillery establishment up to Scale B.

The Commander-in-Chief stated that he differed from some senior artillery officers who thought that the suggested proportion of 6-in. guns to howitzers (eight to 60) was perhaps too great. They pointed out that the Germans had at the most 20 guns to 100 howitzers, and that though the French had a higher percentage of guns, they were trying to get more howitzers.[4] In Sir Douglas Haig's opinion, however, the experience of the British Army was as great as that of any other, and he was convinced that his conclusions were based on sound considerations. Sir Douglas Haig was not alone in his view of this matter. The correct proportion of guns to howitzers was discussed with the French in September,[5] and it was decided to increase the number of 6-in. guns. On 28 September, the Secretary of State for War called the attention of the War Committee to the urgent need for pieces of this nature, so as, if possible, to outrange German guns.[6] Inquiries were made as to the possibility of using guns taken from coast defence, and the Admiralty was asked for help, but the urgent need of guns for arming both merchant ships and cruisers employed in the blockade prevented the Admiralty from giving much assistance.

The Army Council approved the new G.H.Q. programme on 3 October.[7] The extra orders necessitated by the adoption of Scale B were large—600 6-in. howitzers and 240 8-in. or 9·2-in. howitzers—but the Ministry of Munitions reported (9 October) that the latter requirement was covered by orders already placed.

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[1] D.M.R.S. 404. [2] *Ibid.*
[3] O.B. 796/G. in D.M.R.S. 404.
[4] The French had even asked British G.H.Q. for a loan of howitzers in exchange for field guns. (D.M.R.S. 404.)
[5] *Review of Munitions Programme,* August, 1917. (HIST. REC./R/1000/42.)
[6] D.M.R.S. 404. [7] *Ibid.*

Proposals had been made for obtaining a very large number of 6-in. guns, but about the end of September these plans were curtailed. However, on 9 October the Gun Department urged that even if complete equipments were not ordered, extra guns should be obtained.[1] Relining and transit from and to the front took about five months, and as the life of the Mark VII gun was very short, being estimated at 1,200 rounds, it was advisable to keep a large stock in reserve. On 29 October the War Office informed G.H.Q. that twelve 6-in. guns, Mark VI, and twelve Mark VII would eventually be available for each corps. This number would represent a large increase over Scale B, in which the requirement stood at eight per corps.[2]

IV. The Demand for Guns in the Autumn and Winter of 1916–17.

The War Office attached great importance to weight as well as range, and urged that the provision of 12-in. and 14-in. guns should not be postponed.[3] The need for additional artillery was known to be still very serious, and on 25 October, the War Office was informed of the Ministry's intention to instruct contractors to continue at their maximum capacity.[4] On 11 November, however, the matter was still under consideration by the War Office.[5] Meanwhile, an Allied conference had been held, and the urgency of placing new orders was confirmed by a minute of 9 November from Mr. Montagu, now Minister of Munitions: —

> "In anticipation of War Office sanction, I have given instructions that every gun maker in the United Kingdom is to be kept up to a maximum capacity till further notice. Additional plant must be laid down for repair. A promise can be given that we will do our utmost to give gun makers material and labour."

This policy was endorsed by Mr. Lloyd George, then Secretary of State for War.

On 11 November, a memorandum by the Gun Department showed the importance of speeding up and securing continuity in the manufacture and repair of guns. The increased expenditure of ammunition would shorten the lives of the guns, and the Allies needed help.[6] The department suggested that forging and gun steel capacity should be increased in order to meet British requirements, and to help Belgium, France and Russia. More firms should be brought into the work and more labour supplied. Repairs must have priority over new production, as the establishment in the field must be maintained in any case. Proposals for extensions should be submitted without delay, so that firms might maintain their maximum production as well as deal with their allotted number of repairs. Labour should be diluted by bringing in women, and men not eligible for military service.

In September, the War Office had cut down the Ministry's proposals, based on estimated casualties, for increased orders for 18-pdrs.

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[1] D.M.R.S. 404.
[2] D.D.G.(D.) 140.
[3] D.D.G.(D.) 157.
[4] D.M.R.S. 404.
[5] 121/Stores/6074 in D.M.R.S. 404.
[6] *Ibid.*

60-pdrs., 6-in., 8-in., 9·2-in. and 12-in. howitzers, but on 25 November, 1916, the War Office asked for the following additional equipments to be ordered :—

500 18-pdr.
100 4·5-in. howitzer.
100 60 pdr.

The 60-pdr. guns were required to replace 4·7-in. equipments which were being handed over to the Navy. In January 1917, the Ministry was urged to secure punctual deliveries of 18-pdr. guns and 4·5-in. howitzers as the need for them was urgent.[1]

The need for 4-in. and other guns for arming merchant ships was imperative during the autumn of 1916, and a good deal of manufacturing capacity had to be spared to meet the demand. Thus part of the very large programme of 6-in. guns for the Army had to be abandoned, and in November it was arranged that some of the 6-in. guns already ordered should be given to the Navy.[2]

Towards the end of 1916, also, the problem of repair became very pressing. The proposed increase in the expenditure of ammunition made it certain that guns would wear out more quickly than before, and that ultimately repairs would have to be undertaken on a larger scale than was possible at the moment.[3] In December, a letter from G.H.Q. gave information as to the number of rounds already fired by the howitzers then in the field, and the consequent expectation of life for these natures.[4] It was pointed out that although, in June, Sir Douglas Haig had not asked for any new 15-in. howitzers to be ordered, he still wished existing howitzers of this nature to be repaired. G.H.Q. also asked that the design of the 12-in. howitzer might be improved, if possible, so as to lengthen its life, which was very short compared with that of the 9·2-in. howitzer. Meanwhile, a large reserve of the 12-in. howitzer must be maintained.

V. Increasing Demand and Increased Facilities for Supply.

In the spring of 1917 it became clear that the capacity for gun production and repair was insufficient to meet the increasing demand. This led to a re-organisation of the Gun Department, and the transfer of machining capacity from shell work to gun repair, and later to gun manufacture under the direction of Sir Glynn West.[5]

On 1 February, the Minister had submitted to the War Office an estimate of deliveries of new and repaired guns and carriages during 1917, pointing out the difficulties attending gun supply, and that unless materials, machine tools and labour were forthcoming anticipations would not be realised.[6] In the case of repairs, the rate of re-delivery depended on the number of worn and damaged guns sent back from the front for repair.

Steps were taken to hasten deliveries on American orders and to bring in more firms at home, including firms which had hitherto made shells or gun parts. Colonel Embury was appointed to look after

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[1] D.M.R.S. 404.
[2] *Review of Munitions Programme*, August, 1917 ; D.M.R.S. 404.
[3] *See* below, p. 75. [4] D.M.R.S. 404. [5] *See* below, p. 57.
[6] D.M.R.S. 404 ; Notes of Conference of 13 February, 1917.

American deliveries, and a small committee was formed to deal with the situation at home, but a large demand from the War Office for 6-in., 8-in. and 9·2-in. howitzers (24 February), which were required to replace artillery offered to Russia,[1] revealed the critical nature of the situation. The Ministry pointed out (7 March), that firms had been ordered to produce howitzers at their maximum rate and that, therefore, no further production was possible unless capacity at an armament firm became free from repair work later in the year.[2]

Deliveries for the period 1 January to 31 March fell short of anticipations, and, on 19 April, Lord Derby, Secretary of State for War, wrote to the Minister of Munitions (Dr. Addison), expressing great disappointment.[3] The Gun Department was inclined to dispute the War Office conclusions, thinking that probably they were based on verbal and very conservative estimates of deliveries.[4] They explained that delay with the 8-in. and 9·2-in. howitzer was attributable partly to changes in design, while there had been difficulty in getting steel for the 9·2-in. howitzer. Strikes at Elswick and Barrow during April caused a great loss of output. However, a further examination of the position showed that there was a deficiency also in deliveries of 6-in. guns and 4·5-in. howitzers.

VI. The First Programme for 1918 (July 1917).

Discussion of the 1918 programme began in April, when the Ministry asked the War Office to forward its demands as soon as possible, as it was desirable to recover for the land service machining capacity which had been transferred to the Admiralty to meet the urgent demand for guns for merchant ships.[5]

The following table (5 May, 1917), shows requirements on the basis of the increased number of divisions.

ESTIMATED REQUIREMENTS OF NEW GUNS UP TO THE END OF 1918.

	13-pdr. A.A.	13-pdr. 6-cwt. R.H.A.	3-in. A.A.	18-pdr.	4·5-in. How.	60-pdr. C.	6-in. How. C.	8-in. How. and 9·2-in. How. C.	6-in. Gun.	9·2-in. and 12-in. A.	12-in. and 15-in. How.
Number of Guns to be in the Field by 1/1/18	259	132	300§	4,620	1,472	752	1,572	648	232	23	92
25 per cent. Reserve	67	33	75	1,155	368	188	393	—	58	6	23
Total	326	165	375	5,775	1,840	940	1,965	—	290	29	115
Deduct number now available.	229	227	219	4,130	1,124	586	841	—	74	7	45
Required to complete	97	—	156	1,645	716	254	1,124	—	216	22	70
Maintenance to make good wastage up to 31/12/18	75*	45†	15	3,460	955	1,445	1,012	—	630	10	25
Total output required up to 31/12/18	172	—	171‡	5,105	1,671	1,799	2,136	—	846	32	95

* Altered on 20 June to 180.
† Altered on 20 June to 120.
§ Includes 180 with sections on Home Defence.
‡ 100 added on 7 July.

[1] Sixteen 6-in. howitzers, eight 8-in. howitzers and four 9·2-in. howitzers monthly for six months. (D.M.R.S. 404.)
[2] D.M.R.S. 404. [3] D.M.R.S. 434. [4] D.M.R.S. 404. [5] D.M.R.S. 535.

Repairs were to be estimated according to ammunition expenditure at the rate asked for by G.H.Q. on 23 September, 1916. The total expenditure was expected to depend mainly on the number of new and re-lined guns available.[1] The War Office hoped that deliveries would begin before 1918, and in June the Ministry estimated that for the first quarter of 1918 deliveries would exceed requirements except for the 4·5-in. howitzer. The 6-in. howitzer was growing "daily more popular,"[2] and many demands were made for more ammunition for this nature.

VII. The Growing Demand for Long Range Guns.

During the summer of 1917 there was an imperative call for long range guns.[3] Deliveries of those already ordered had been disappointing for various reasons, the chief being lack of steel forgings, changes in design, delay at proof, and delay in reaching the stage of rapid production in firms new to gun work. As regards the 9·2-in. guns on railway mountings, delivery of the Mark X equipments was due about the end of March, but on 16 August five new and two repaired guns were still undelivered. Many inquiries were made as to when the guns would be forthcoming and whether it would be possible to hasten delivery. The 9 Mark IV (35 calibre) guns were also very late; delivery was expected from the middle of April to the middle of June, but only began in August. The 14 Mark XIII guns, delivery of which was expected to begin in August, were also behind time.

Mr. Churchill was most anxious to develop the supply of long range guns. In a minute of 21 September, 1917,[4] he said that he was convinced, after discussion with G.H.Q., that range was now the really vital factor. Though for ranges up to 15,000 yds. the British artillery establishment was much better than the French, for longer ranges the position was reversed, and the French and the Germans were both working up to a very high standard, and had taken guns from their fleets. It was probable that in 1918 the enemy would be able to shell towns, billets, etc., far behind the lines, not as hitherto with a few shells, but with a steady fire from converging guns. The only way to deal with this was to have similar guns which could put the enemy's out of action. Consultation with French Generals confirmed Mr. Churchill's views; the French programme for 1918 comprised about 1,800 long range guns, some new, some from America, some taken from fortresses and ships. Many of the guns would have very primitive mountings, and Mr. Churchill thought that the British ought to use simple and improvised mountings as well as those of more perfect construction. Thus, if fairly good railway facilities were available, guns could be concentrated at any given point. The Minister wished the whole French plan to be examined carefully, as to the numbers of guns, methods of mounting, railway arrangements, and personnel

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[1] D.M.R.S. 535. [2] *Ibid.*

[3] D.M.R.S. 404A. Anti-aircraft guns were also needed urgently in the latter half of 1917. *See* Vol. X, Part VI.

[4] HIST. REC./R/300/113.

and labour required.[1] Carriages, Mr. Churchill continued, were the limiting factor. Ammunition could be obtained and guns could be secured from the British and American Navies, since the evolution of new types of craft involved the existence of a large surplus of discarded naval artillery.

In response to the Minister's request for proposals as to the best method of increasing the supply of carriages, it was found that by delaying a number of 6-in. gun carriages and, if necessary, five 12-in. howitzer equipments, it would be possible to obtain 68 heavy gun mountings capable of simultaneous action by the middle of August, 1918.[2] The Minister sanctioned this arrangement on 6 October.[3]

The programme for mountings, which were to be made to suit several natures of heavy guns, the orders being divided between Messrs. Vickers and Messrs. Armstrong Whitworth, provided for 66 guns as follows :—

6	14-in. guns	on existing type of railway mountings.
8	12-in. guns	
25	9·2-in. guns	
10	13·5-in. guns	on semi-mobile mountings.
12	12-in. guns	
5	10-in. guns	

Mr. Churchill wished to work for a still larger programme that would provide 100 heavy guns ready for simultaneous action by the middle of August, 1918. It was found that continuation orders would give a total of 100 heavy guns and mountings which might be ready by October, 1918, while delivery by the middle of August was possible if the immobile mounting designed by Messrs. Armstrong were accepted.

On 3 November the Minister expressed his desire to be assured that the War Office and G.H.Q. would endorse this long range gun programme. The Master-General of the Ordnance replied on 10 November that he feared G.H.Q. would not like the semi-mobile or immobile mountings. On 23 November G.H.Q. wrote declining the immobile mounting, and this was therefore dropped.[4]

VIII. The Position at the End of 1917.

By the end of 1917, several factors had combined to facilitate the execution of the gun programme. An improved method of handling gun bodies was being employed and the War Office estimates of wastage had proved excessive, while from April, 1917, the supply of guns to Russia had ceased.[5]

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[1] The sub-committee appointed by the Minister to investigate the position reported that the result of their inquiries did not quite bear out the French figures. It was found, too, that some of the French mountings were more elaborate than our own. Moreover, it was impracticable to use our long range guns without recoil mechanisms. (Hist. Rec./R/1200/30.)

[2] D.M.R.S. 535. G.H.Q. was known to attach great value to the 12-in. howitzer, but the delayed production suggested by the Ministry would still meet G.H.Q.'s requirement.

[3] D.M.R.S. 535. [4] D.M.R.S. 535 II. [5] D.M.R.S. 404, 535.

Again, during the period, August to November, 1917, plant in munition factories had been re-arranged so as to increase production. Many firms had been making both guns and shells, a method which was wasteful of space and management. Plant for 60-pdrs. and for repairs of 18-pdrs. was now concentrated in factories at or near Leeds, while the Nottingham Ordnance Factory was to work on new 6-in. guns exclusively. By these and similar changes, it was estimated that a temporary set-back in production would be outweighed substantially in the long run.

The Minister decided, however, to continue production at the maximum rate, in addition to all repair schemes, since any surplus over British requirements would go to the Allies, who needed far more than we should be able to supply (30 October, 1917).[1] The following table gives a summary of the gun position with a view to the 1918 campaign.

Nature.	*Prospective Position in* 1918.[2]
1·59-in. guns	Satisfactory.
2·75-in. guns	,,
13-pdr. 6-cwt. guns	,,
13-pdr. 9-cwt. guns A.A.	,,
3-in. 20-cwt guns A.A.	100 guns short.
3·7-in. howitzers	Satisfactory.
18-pdr.	,,
4·5-in. howitzers	,,
60-pdr. guns	200 carriages short.
6-in. 26-cwt. howitzers	Satisfactory.
6-in. guns, Mk. VII.	,,
6-in. guns, Mk. XIX.	100 guns short.
8-in. howitzers	Satisfactory.
9·2-in. howitzers	,,
9·2-in. guns	,,
12-in. guns	,,
12-in. howitzers	Not quite satisfactory.
14-in. guns	Satisfactory.
15-in. howitzers	,,

The programme of ammunition wagons and limbers was again revised, and on 11 November the War Office forwarded amended requirements showing a substantial increase in the demand for 18-pdr. and 4·5-in. ammunition wagons and wagon limbers.[3]

IX. The 1918 Programme.

Requirements for artillery during 1918, showed a rather sharper distinction than usual between the evolution of a normal programme for the future, and the satisfaction of immediate or emergency needs. The German offensive, beginning on 21 March, resulted in the loss of so many guns that their replacement became a matter of supreme importance and urgency.

[1] D.M.R.S. 535 I.

[2] General Headquarters proposed to fire ammunition at a reduced rate during the winter of 1917–18, so as to spare the guns.

[3] D.M.R.S. 535. There was a decrease of 2,000 18-pdr. ammunition wagons and wagon limbers and of 700 4·5-in. ammunition wagons and wagon limbers.

On 15 February, the War Office opened the question of the new gun programme. Despite strikes at Glasgow and Sheffield in January, recent deliveries from the Ministry had been good, and it was expected that during the summer, more equipments would be available than were needed for the batteries in the field.

The following table set out the War Office requirements as corrected on 1 March.[1]

TOTAL REQUIREMENTS (EXCLUDING MAINTENANCE) FROM 1 FEBRUARY TO 30 JUNE, 1918.

Nature.	Still required for arming units and for reserve.		For replacements of non-repairable casualties up to 30/6/18.		To meet outstanding demands including Palestine and Egypt and Allies.		Total.	
	Guns.	Carriages.	Guns.	Carriages.	Guns.	Carriages.	Guns.	Carriages.
18-pdr. ..	—	315	161	601	263	45	424	961
4·5-in. How.	233	98	177	380	40	43	450	521
60-pdr. ..	239	93	17	20	76	56	332	169
6-in. How.	420	420	93	95	5	3	518	518
8-in. Mk. VI.	22	22	12	25	67	69	139	150
8-in. Mk. VII.	15	15			21	19		
9·2-in. Mk. I. ..	22	22	12	15	77	74	224	220
9·2-in. Mk. II. ..	60	60			53	49		
12-in. (Rail)	9	9	6	1	2	1	17	11
12-in. (Road)	7	7	6	1	2	1	15	9
6-in. Gun ..	95	55	—	—	5	—	100	55

In accordance with the request of the War Office, a joint conference was held on 18 February, to consider how far new types should be introduced. It was decided to eliminate the old types of 8-in. and 9·2-in. howitzers as soon as possible after completing the establishment, and (18 March), to order no more of several types of guns (for instance, the 1·59-in. Crayford), after delivery of those already ordered.

The Ministry outlined the new gun policy for the year on 12 March. The shortage of raw materials had entailed a reduction of the former programme, but the existing programme would cover War Office requirements and also allow for the supply of a number of 8-in. and 9·2-in. howitzers promised to America.[2] The War Office had decided to reduce establishment and reserve, and ammunition supplies also were to be reduced, thus lessening the number of casualties due to wear.

Various proposals were made as to the method and rate of slackening production and of substituting new types. It was suggested (12 March), that 6-in. howitzer carriages should be manufactured at a lower rate from September onwards, that production of 6-in. Mark XIX carriages

[1] D.M.R.S. 535.

[2] The War Office wished these howitzers to be maintained and supplied with spares exactly like the howitzers in the British Army. (D.M.R.S. 535.)

should be reduced as soon as possible after April, and the plant turned over to 8-in. howitzer Mark VII carriages, while repairs of 9·2-in. howitzers might be reduced to 12 per month for November and December. The 6-in. Mark VII gun should be produced at the existing rate up to September, when orders would be complete. Repairs could not be carried out on the scale formerly proposed, but must be reduced as little as possible. As regards the 8-in. howitzer, if America would accept the Mark VI type, all guns of Marks I–VI were to be repaired. Reduction in the output of the old types of 18-pdr. and 60-pdr., the 4·5-in. howitzer, and the 6-in. howitzer, mainly in the latter half of the year, were suggested, output of the new types beginning then and increasing later on.

The Controller of Gun Manufacture, however, thought (19 March) that the labour and machines employed on these types ought to be conserved in case of a sudden demand for new types.[1] No new steel need be used for forgings for the old Marks, as sufficient forgings were already in existence. Considering, moreover, the possibility of a reverse in France, involving serious loss, it was a sound principle to continue the manufacture of material already in hand.

In March the Minister urged the need for producing more carriages, especially for 18-pdr. guns, for 6-in. howitzers and for 9·2-in. guns.[2]

About the beginning of April[3] a conference was held at General Headquarters to discuss artillery and ammunition programmes. Requirements of several of the main types of guns were considered. It was decided that the full establishment of 60-pdrs. must in any case be maintained, though longer range was very desirable, and the new type should be substituted so far as numbers were not reduced.[4] In the case of 18-pdrs., the new type, of which 350 equipments had been ordered, was to be substituted if found a success.[5] Meanwhile General Headquarters agreed to accept 100 18 pdr. guns on 4·5-in. carriages, and the Minister was asked to hasten delivery.[6]

The valuable 6-in. gun was still not available to the extent desired by G.H.Q., and as it had a very short life a bigger reserve was most desirable. The supply of heavy long-range guns also did not meet the needs of the Army in France. Only 21 9·2-in. guns had been received, against a requirement of 34, and G.H.Q. insisted that the latter number must be reached, as the establishment was fixed at twenty-nine, with eight in reserve.[7]

General Headquarters stated (9 April) that the new pattern of 6-in. howitzer was too heavy, and the Ministry was asked to cancel supply.

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[1] D.M.R.S. 535 II.

[2] During the month an urgent demand arose for carriages and limbers. On 8 March the Ministry was asked to order 250 8-in. Mark III limbers to make up for issues to America. On 15 March the War Office put forward a large demand for Anti-Aircraft guns. (121/Stores/8019.)

[3] D.M.R.S. 535 II.

[4] The Ministry had ordered in anticipation 150 mechanisms, 200 guns and 100 carriages.

[5] The new type had a range up to 9,200 yards.

[6] These proved unsuccessful on trial and were given up.

[7] There were also six 18-in. howitzers on order. (D.M.R.S. 535.)

In the spring of 1918 a special committee was formed to investigate the possibility of mechanical traction for field guns. It was suggested at the conference at G.H.Q. on 11 April that Ford tractors might be used instead of horses. If this method were practicable, it would mean a considerable saving in shipping.[1]

In April, G.H.Q. reported that the carriage position was satisfactory. The supply of carriage limbers, wagon limbers and ammunition wagons was discussed by the Ministry in May. Although the original War Office demands had been reduced, the Controller of Gun Manufacture and other Ministry officials opposed the cancellation of orders placed in excess of War Office demands. It was urged that the Army's losses might not yet be known in full, that cancellation would involve loss to the Ministry, and that increased demands were certain in 1919, while supply could not be reorganised at a moment's notice after being allowed to drop.[2]

X. The Increased Demand due to the German Offensive.

The events of March and April, 1918, resulted in a serious change in the artillery position. The German offensive launched on 21 March was followed immediately by urgent demands from G.H.Q. On 22 March, following a message from France, the Controller of Gun Manufacture was asked to hasten 300 18-pdr. breech blocks and 200 carriages, and as many carriages for 4·5-in. howitzers as could be obtained.[3] In the first fortnight of the offensive the British lost nearly a thousand guns.

APPROXIMATE CASUALTIES TO GUNS, HOWITZERS AND CARRIAGES ON THE WESTERN FRONT 20 MARCH TO 31 MARCH, 1918.[4]

	Guns.	*Carriages.*
13-pdr. Anti-Aircraft	8	8
3-in. 20-cwt...	—	—
15-pdr. B.L.C.	No reliable figures available.	
18-pdr. Q.F.	513	497
4·5 in. Howitzers	163	163
60-pdr. B.L.	66	63
6-in. Howitzers	166	161
6-in. Gun	11	11
8-in. Howitzers	30	32
9·2-in. Howitzers	15	16
12-in. Howitzers (Railway)	2	2
12-in. Howitzers (Tractor)	1	2
15-in. Howitzers	—	—
	975	955

The sudden demand for replacement was most difficult to meet. The United States Government had, of course, placed many orders in America, while the Admiralty had a call on munitions capacity at home. The output of several British firms (for instance, Messrs. Armstrong & Vickers) had for various reasons fallen below anticipations,[5] while the new Military Service Bill threatened to remove

[1] D.M.R.S. 535 II. For further details *see* Vol. XII, Part IV.
[2] *Ibid.* [3] D.M.R.S. 535, 535, II. [4] 121/Stores/8573.
[5] The estimates for deliveries of 6-in. (Mark XIX) guns, and of 8-in. and 9·2-in. howitzers and of 3-in. (20 cwt.) guns had to be reduced. (D.M.R.S. 535 II.)

many young skilled men from the factories. In order to maintain supply it would have been desirable to exclude both from recruiting and from volunteering men engaged on breech mechanisms, long range gun equipments and certain other classes of work. This, however, was quite impracticable, since the Army in France was short of personnel. Owing to losses there were urgent demands for breech mechanisms,[1] the following additional programme for these parts being put forward by the War Office on 17 April.[2]

13-pdr., 9-cwt.	100
13-pdr., 6-cwt. and 18-pdr., Marks I and II	1,000
4·5-in. Howitzer	200
60-pdr.	200
6-in. Howitzer	800
6-in. Gun, Mark XIX..	60
8-in. Howitzer, Marks VI and VII	330
9·2-in. Howitzer, Mark I	160
12-in. Howitzer, Mark IV	8

The Ministry of Munitions considered this programme impracticable on account of the shortage of machine tools and labour, and also criticised it in detail. For instance, the demand for 4·5-in. howitzer mechanisms seemed unjustifiable on existing estimates. The Ministry representatives explained the situation at a conference on 19 April.[3] If labour employed on mechanisms were not withdrawn for the Army it was thought that the need might be met. An effort was made to obtain help from America, and on 24 April a cable was sent inquiring whether the Bethlehem and Midvale Companies could supply the following mechanisms :—

1000..	18 pdr. Mark I.
350	8-in. Mark VI.
150	9·2-in. Mark I.

The 8-in. and 9·2-in. howitzer mechanisms were, however, not ordered from America, being obtained from Messrs. Armstrong and Vickers.

At the end of May the War Office reconsidered, in conjunction with the Ministry, the demand put forward on 17 April. The following orders for breech mechanisms were sanctioned for delivery between 1 May and December, 1918 (23 May, 1918) :[4]

18-pdr., Marks I and II	1,500
18-pdr., Mark III	250
4·5-in. Howitzer	800
60-pdr., Mark I	250
60-pdr., Mark II	160
6-in. Howitzer	900
6-in. Gun, Mark XIX	280
8-in. Howitzer, Mark VI	48
8-in. Howitzer, Mark VII	205
9·2-in. Howitzer, Mark I	48
9·2-in. Howitzer, Mark II..	100

[1] Even before the attack began, the War Office had seemed anxious about the supply of these parts. (D.M.R.S. 535.)
[2] D.M.R.S. 535 II. [3] *Ibid.* [4] *Ibid.*

The shortage continued throughout the summer. In May an appeal for help was made to the Admiralty. In June the 6-in. gun and the 8-in. and 12-in. howitzers were still below requirements, and on 15 July the Ministry forwarded to the War Office a table comparing demands with anticipated supply which showed a large deficit for nearly all natures. The Ministry realised the position, but pointed out that even the anticipated deliveries were precarious, and depended on the supply of machine tools and labour. Special sources were being tapped for the very urgent requirements, but even so no appreciable deliveries could be expected during 1918.[1]

The demand for gun carriages in the spring of 1918[2] was equally urgent. Inquiries were made as to whether they could be obtained from America[3] (27 March, 1918), but little help was available. 18-pdr. carriages were wanted at once, but the United States Government had placed orders which absorbed manufacturing capacity, and would not give up any carriages for which guns were available,[4] though it was hoped to procure for Great Britain any carriages in excess of guns then completed for the United States.[5] It was thought that by ordering certain carriages in America, allocations of heavy howitzers to the American Expeditionary Force could be hastened, but it was found that deliveries would not be sufficiently quick. The Midvale Company offered to deliver 8-in. howitzer carriages from November onwards, but as the howitzer was probably to be withdrawn in the autumn, the Ministry thought this delivery too late to be useful (30 April, 1918). It was believed that 9·2-in. carriages would be produced in England at the same rate as the guns, and thus there would be no advantage in placing orders in America.

XI. The Programme for 1919.

Consideration of the 1919 programme dates from the War Office letter of 15 December, 1917.[6] The Army Council stated the proposed strength of personnel as only 23 Corps (69 Divisions) on the Western front, and 16 Divisions in other theatres. The following table sets out the proposed requirements in artillery :—

Nature.	Equipments.		Total.
	Western Front.	Minor Theatres.	
18-pdr.	3,516	576	4,092
4·5-in. Howitzer	1,104	192	1,296
60-pdr.	552	96	648
6-in. Howitzer	1,380	160	1,540
8-in. Howitzer	276	16	292
9·2-in. Howitzer	276	—	276
12-in. and 15-in. Howitzer	92	—	92
6-in. Gun	184	8	192
9·2-in. Gun	24	—	24
10-in. Gun	1	—	1
12-in. Gun	8	—	8
14-in. Gun	4	—	4

[1] D.M.R.S. 535, II. [2] D.M.R.S. 535. [3] D.M.R.S. 535, II [4] *Ibid.*

[5] These carriages would have to be fitted with certain parts on arrival in England. [6] D.M.R.S. 535.

At a conference at G.H.Q.[1] (11 April, 1918), it was stated that the limiting factor in 1919 would be personnel. The suggestion that a large establishment of guns could be maintained by moving personnel from one firing point to another as required, was only practicable up to a certain point, since the movement of personnel and ammunition was a more serious transport problem than the movement of a gun. The lives of guns, except of the 60-pdr. and the 6-in. guns, which had not much of their lives remaining, were reported to be in a good state.

The heavy gun programme for 1919 was discussed at a conference on 22 April.[2] With regard to the 6-in. gun, it was decided to ascertain whether G.H.Q. agreed in the continuance of the existing establishment of 102 Mark XIX and 57 Mark VII. More guns would be available during the winter, and, if desired, the establishment of Mark XIX could be increased at the expense of 8-in. Mark VII carriages. It was agreed that the range of the 9·2-in. guns should be increased if possible.

A further conference was held at the Ministry on 21 May.[3] The Minister stated that during 1918 the highest point in weight of metal would be reached. The main reason for the decline anticipated in 1919 was shortage of shipping; material and labour also being scarce in a lesser degree. Range was therefore the vital factor, and it was necessary to consider various methods of exploiting it.[4] Longer range for the establishment as a whole might be obtained by increasing the proportion of guns to howitzers.

The Minister later urged the importance of supplying at least two 18-in. howitzers to destroy bridges, canals, railway centres and similar objects with certainty at 24,000 yards range, and the Admiralty, which was making these guns, promised to hasten delivery as much as possible.[5]

On 16 June, G.H.Q. wrote with reference to previous requests, to remind the Ministry again of the urgent necessity of developing long range artillery, both guns and howitzers. It was absolutely vital to overtake the Germans who now had greater accuracy at long range. The German 15 c/m gun, firing false capped shell for instance, was accurate at 25,000 yards.[6]

On 6 July, the Ministry forwarded, at the request of the War Office a statement of the experiments then being carried on with a view to increasing the range of British artillery. The inaccuracy of the British 60-pdr. and 6-in. howitzer, at long range was realised and steps were being taken to remove it. Research and experience also gave hope of improved ballistics.

Although the programmes for 1919 did not materialize and have no practical importance, they are interesting as reflecting artillery conditions during the last year of the war. The British Armies were at their maximum strength, both in personnel and artillery. Had the war continued, the British position must have become gradually

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[1] D.M.R.S. 535 II. [2] *Ibid.* [3] *Ibid.* [4] *See* below, p. 49. [5] D.M.R.S. 535 II.

[6] Some of these guns were captured, and proved to be light field guns mounted on a light field mounting, and outranging the British 6-in. gun by 5,000 to 6,000 yards.

weaker, and apart from the growing strength of the Americans, all would have turned on the relative decline of the Allies and the enemy. Artillery, particularly long range artillery, was bound to be one of the most decisive factors and the demand for heavy howitzers of great destructive force had given way to the demand for long range guns.

The latter part of the war showed a reversion to the older idea of warfare as a series of battles, each with a definite result and bringing decisive advantage to the victor. In every such battle, artillery played of necessity a highly important part. The war, as Mr. Churchill pointed out, had developed into a "series of climaxes," and the policy must be to develop the establishment of guns so that a tremendous fire could be concentrated at a particular point. Surplus guns ought not to be treated as idle capital, merely relieving the manufacturing programme, but might be used to arm new Divisions which could hold the line at quiet spots, releasing more "shock" troops for the points of attack.

It is curious to note that though, in June, 1916, Sir Douglas Haig had advocated simplicity in the gun establishment, at the end of the war there were as many types in use as in 1916.

CHAPTER IV.

REVIEW OF THE CHIEF CHANGES IN GUN DESIGN.

I. The Design of Guns.

After the formation of the Ministry of Munitions the responsibility for the design of new equipments and of modifications to existing equipments rested with the Director-General of Munitions Design. Designs were prepared by the Ordnance Factories, Woolwich, or by one of the armament firms, and were normally considered by the Ordnance Committee before approval by the Director-General of Munitions Design. The Chief Superintendent of Ordnance Factories was often consulted when designs were under discussion. The Design Department worked in close touch with General Headquarters, and commissions, often including manufacturers' representatives, were sent to France to examine specific problems on the spot, and to submit reports and proposals.[1]

The individual contributions of Woolwich and the armament firms to gun design may be briefly summarised here. Woolwich, which carried out all repair work until the summer of 1916, designed most of the methods of repairing worn guns, and a new pattern of breech mechanism, introduced in 1918. The Ordnance Factories also produced modifications to existing types such as the alteration which gave 30° elevation to the 9·2-in. mounting.

Of the armament firms the most versatile in gun design was undoubtedly Messrs. Vickers. This firm specialised in mobile field equipments, and designed the 6-in. 26 cwt. howitzer, the 8-in. howitzer Mark VI, the first of that nature to fire from its own carriage, and Mark VII, the 6-in., 35 calibre gun, the 9·2-in. howitzer, and the 12-in. road howitzer.

Messrs. Armstrong, Whitworth designed the 9·2-in. 35 calibre gun, the 12-in. howitzer railway equipment and a number of railway mountings, including those for the 9·2-in., Mark X and 35 calibre, the 12-in. and 14-in. guns. Semi-mobile mountings for long range guns were also designed by Messrs. Armstrong, but they were not accepted by General Headquarters

The 4·5-in. howitzer was designed by the Coventry Ordnance Works, who, in conjunction with Messrs. Vickers, produced a new design for this howitzer which was accepted in the autumn of 1917.[2] The firm also worked on the design of 15-in. howitzers.

Messrs. Beardmore designed an 8-in. howitzer and a 10-in hyper-velocity gun, but neither was accepted.

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[1] For a full account of the evolution of the Design Department *see* Vol. IX, Part II, Chap. VI.

[2] D.G.M.D/G/0200.

Design work during the war was particularly difficult owing to the urgency of the need for supply. Simplicity of manufacture and repair were often more vital than perfection of quality.[1] The best materials were scarce or unobtainable, there was a dearth of skilled labour, and manufacturers were sometimes unwilling to introduce changes. Modifications had to be kept down to the minimum, imperfect designs perpetuated and makeshifts devised at very short notice, and in addition there was the danger of creating one defect while curing another. Thus range might be improved by introducing certain alterations which would then make the equipment too heavy, or a long range shell might be designed only to prove inaccurate and ineffective.

While the Ministry of Munitions was responsible for supply new designs were evolved for 12-in., 9·2-in. and 8-in. howitzers, 60-pdr. and 18-pdr. guns, while railway mountings were designed for the 18-in. howitzer, 14-in., 12-in. and 9·2-in. guns, and a mobile field mounting for the 6-in. gun.

The new road and railway mountings made it possible to employ in large numbers guns and howitzers which, owing to their weight and size, it had hitherto been regarded as impossible to use in the field.

> "The 12-in. howitzer, weighing about 80 tons, has been so designed that it can be moved about behind the Army with ordinary traffic.
>
> " Thus enabled to come into action close behind our front line, three or four shells from this piece, probably the most accurate shooting weapon ever designed, will totally destroy an enemy battery up to a distance of 8½ miles."

Similar improvements were made in the 18-pdr. field gun. At the beginning of the war the range of this gun, without sinking the trail, was limited to 6,500 yards, but in the latest type a range of 9,500 yards was obtained without any increase in weight. The springs used in the earlier equipments to run the gun into its firing position after recoil were replaced by compressed air, which rendered the gun carriage much steadier and increased the rate of fire.

Mechanical devices were also introduced to compensate for the effect of wear in the gun on its shooting and to allow for many other corrections which formerly had to be laboriously calculated. Gun carriages were also fitted with electric illuminated gear, in the hope that firing might be carried out as easily by night as by day.

II. Guns and Howitzers.

The relative value of guns and howitzers was a problem of some difficulty. The French, probably as the result of the Napoleonic tradition, did not share the British faith in howitzers as compared with guns. The 6-in. was the smallest howitzer of which the French approved, but the British valued highly the 4·5-in type, which proved very useful at Mons and elsewhere. The British used howitzers as well as guns for counter-battery work. Points in favour of a howitzer

[1] Hist. Rec./R/1141/42.

rather than a gun against such targets were its greater mobility for the same weight of shell and the greater ease with which fire could be observed, particularly by an aeroplane. A howitzer could be stationed in hollows impossible for a gun, and fired in crowded areas where the blast of a gun would sweep away everything in front of it.[1] Another advantage of the howitzer was its comparatively long life, that, for instance, of a 6-in. howitzer being over 10,000 rounds as compared with about 1,900 rounds for the 6-in. gun.

Owing to changes introduced during the war, the distinction between guns and howitzers grew much less sharp; the later howitzers were longer than the early types; guns were fired at high angles of elevation, while the adoption of new types of shell increased the ranges of both.

III. Recoil and Recuperator Systems.

During the war the recoil and recuperator systems of practically all equipments showed serious defects,[2] which were remedied after prolonged experiments with various types.

The 6-in. howitzer was the first modern British equipment to be fitted with an air recuperator of the Scheider pattern. In September, 1916, a design of air recuperator produced by Messrs. Vickers was approved for the 18-pdr. gun, and supply began early in 1917, the innovation proving a success once early difficulties with the air pressure had been overcome, and increasing the rate of fire by improving the steadiness of the equipment. The running-out springs previously used had been a source of anxiety during the Battle of the Somme, and no great improvement had been effected by fitting them with an oil tank.

The buffer of most equipments also gave trouble. The liquid originally used was a mixture of glycerine and water, but this was not altogether satisfactory,[3] and caused wear on the piston rods. Oil, which was first tried in the 9·2-in. howitzer in 1915, was found to give good results and was eventually adopted for all land service guns and howitzers.[4] Filling tanks were fitted to 18-pdrs. in 1916 and proved satisfactory;[5] in October a gravity tank for the 9·2-in. howitzer was approved, and by the beginning of 1918 similar tanks had been added to the 6-in. 26 cwt. howitzer, the 8-in. howitzer and the 6-in. gun.

Leakage, however, was worse with buffer oil than with the glycerine and water mixture. During 1916 leakage had been a serious difficulty owing to the heat of rapid fire and the inexperience of gun detachments. The provision of an oil tank did not cure this defect, as the oil leaked

[1] HIST. REC./R/1141/42.

[2] For instance, in October 1916, General Headquarters reported that every 18-pdr. had to be withdrawn once in three months owing to the defective design of the buffer and recuperator system. (D.G.M. D/G/762.) In September, 1917, it was reported that 60-pdr. control cylinders had often broken and put guns out of action. (D.G.M.D/G/1601.)

[3] During the summer of 1916 the working surfaces of recuperator cylinders were injured by the impure glycerine used, and thus leakage occurred.

[4] *Ordnance Committee Minute*, 11, 915.

[5] D.G.M. D/G/160.

from the gland, the packing of which worked loose.[1] It was necessary to have a recoil indicator, and an easy method of tightening the gland. The question of the material to be used for gland packings caused a good deal of discussion. Originally packings were made of leather, but in 1916 Messrs. Vickers produced a type made of hydraulic rubber. This pattern was adopted for 6-in. and 8-in. howitzers, but at the end of the year had been pronounced a failure with heavy howitzers. In the following February it was pointed out that the use of oil instead of glycerine affected the question, and that rubber corroded steel surfaces and roughened the steel. The rubber also stretched in use, and the packings often cracked before firing. Anhydrous leather of the best quality was considered the most satisfactory material.[2] The use of rubber was, however, sometimes permitted as an alternative to leather, and Dick's packing (made of hemp, asbestos and wire) was used in some cases.

Other points in buffer design also had to be considered. The single valve key type in the 18-pdr. and the double valve key type in the 60-pdr.[3] were unsatisfactory, and the grooved buffer was no better. In the 18-pdr. it caused wear of the piston, and was considered inferior to the rotary valve type. A committee sent overseas recommended at the end of 1916 that the grooved buffer should not be made for new equipments. A year later it was reported that the double valve key type (as in the 60-pdr.), was an improvement, but that the rotary valve type, with two parts, was considered the best.

The design of piston heads was another troublesome question. In August, 1916, it was suggested that a cast iron head should be used for the 18-pdr., but this had been rejected in favour of a long metal type. However, at the end of the year, the committee which went to France recommended the use of this or the split ring pattern. The same designs were suggested for trial in existing 60-pdrs. with grooved buffers.[4] In 1917 Messrs. Vickers designed a new piston for the recuperators of the 6-in. Mark VIII gun, the 6-in. 26-cwt. howitzer and the 8-in. howitzer, Marks VI and VII.

The floating piston was first applied to the air buffer of the 9·2-in. howitzer. In the autumn of 1917 the Ordnance Committee recommended this type for the 60-pdr., Mark II.[5]

IV. Breech Mechanisms.

Important changes were made in the breech mechanisms or firing mechanisms of several natures. After the battles of Messines and Arras it was found that vents of 6-in. 26-cwt. howitzers wore out more quickly than they could be replaced, owing to the use of friction

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[1] The piston expanded and worked into the grooves, then cooled and contracted, leaving larger orifices and so lengthening the recoil.

[2] *Ordnance Committee Minute* 12, 878.

[3] Defects in the 60-pdr. system were intensified by an increased rate of fire and expenditure of ammunition.

[4] In September, 1917, G.H.Q. reported that cast iron pistons were replacing those of manganese bronze in 60-pdr. grooved buffers. (D.G.M. D/G/1601.)

[5] Vickers' piston had been satisfactory in the 18-pdr. Mark III.

T tubes. This difficulty was overcome by the use of rifle-firing mechanisms firing small arms cartridges. By June 1917, rifle-firing mechanisms of Royal Gun Factory design had been approved for certain marks of 60-pdr. gun and 8-in. howitzer, and in September G.H.Q. reported that on the whole they were satisfactory.[1]

The Martini-Enfield pattern of firing gear was not solid enough for rough wear, and in March, 1918 was superseded in the 6-in. 26-cwt. howitzer, and subsequently in all howitzers. The new pattern was designed by the Royal Gun Factory, and, like the Martini type, would take small arms cartridges. A percussion firing gear, like that in the new pattern of 60-pdr., was adopted for the 6-in. Mark XIX gun in May, 1918, thus simplifying the breech mechanism.[2] By June, 1918, a new design of firing gear was practically complete for all heavy guns and howitzers on field carriages, except the 9·2-in. howitzer.[3]

V. Increase of Range.

During the war the value of long range artillery was greatly increased by the development of aircraft. Observation from the air made it possible to direct a destructive fire at points far behind the enemy's lines, and, as a result, artillery was demanded with far longer range than had ever been contemplated before.

The Germans were the first in the field, and in the autumn of 1914 had used heavy howitzers to bombard the trenches of the Allies, who had then very little artillery of sufficient range to reply. The German tactics at Verdun during the spring of 1916 demonstrated the urgent need for longer range artillery. The British forces had comparatively few long range guns in the field, and the existing programme provided chiefly for heavy howitzers, few of which exceeded 11,500 yards in range. A few 9·2-in. guns, with a range of 13,000 yards, had however been ordered, and also two 12-in. guns, the only type with a really long range. On 24 June, 1916, Sir Douglas Haig asked for increased range for nearly every nature in the British service. On 17 July, in a memorandum to the Minister, General Du Cane summarised the various purposes for which long range artillery was required. Medium and heavy howitzers were needed for bombarding enemy trenches. Long range guns, notably 6-in. guns, were wanted for counter-battery work,[4] and also for bombardment beyond the range of howitzers, so that fire might be concentrated, for instance, on the area where troops assembled before coming up to the front line. Special long range guns were needed for attacking objects such as railway stations at a great distance, and, in the future, guns of very large calibre might be required for retaliatory bombardment of German towns.

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[1] D.G.M. D/G/1601.

[2] The firing gear of this gun had given trouble. No satisfactory breech mechanism had been designed, and V.S.P. tubes were considered essential to prevent the life of the gun from being shortened considerably. V.S.P. tubes were often unsatisfactory. (HIST. REC./R/1000/61.)

[3] Breech mechanisms had not been used at first for the heavier guns and howitzers.

[4] In January 1918, it was estimated that long range guns with heavy shell caused 60 per cent. of the damage to enemy heavy and field artillery.

From this time to the end of the war, great and continuous efforts were made to improve the range of British artillery. In June, 1917, the Commander-in-Chief again emphasised the importance of this matter, drawing special attention to the need of a new field artillery equipment with longer range, and of new long range howitzers which should ultimately replace the older marks.[1] In the late summer and autumn the provision of long range guns was considered in great detail by the Ministry of Munitions, while in 1918 the provision of hyper-velocity guns, such as that used by the enemy for bombarding Paris, became one of the foremost questions of the day.

A certain amount of long range artillery was obtained by taking guns from the Navy or from coast defence and providing them with field mountings. Thus the 6-in., Mark VII, was a coast defence gun on an extemporised carriage.[2] Twelve-inch and 9·2-in. naval guns, also were sent to France on railway mountings,[3] the use of which, first introduced during the war, facilitated transport and gave a wide traverse and a good range, in which respects they were superior to road mountings.

Besides the use of special long range ammunition, such as false capped and stream line shell, which is treated elsewhere,[4] there were various methods of improving the range of guns. In many cases the length of the gun was increased; for instance, the 8-in. howitzer, Mark VI, was of 14·7-in. calibre, but Mark VII was of 17·3. Similarly, the Mark II 9·2-in. howitzer was 4·06 calibres longer than the Mark I. Range was improved also by increasing the elevation at which the gun was fired. For instance, the Mark IV 18-pdr. on Mark III carriage had a range of about 9,000 yards at 30° elevation, but a later pattern, allowing 37° elevation was expected to give 1,500 yds. more with improved shell. The 12-in. gun, Mark IX, at 30° elevation had a maximum range of 28,000 yards, but a mounting with 35½° elevation gave 30,000 yards. Another important factor was the strength of the charges used.[5] By increasing the muzzle velocity of the gun, the shell could be made to range further.

In theory, better long range weapons would be obtained by designing new equipments than by adapting existing patterns, but the former method might involve such disadvantages as loss of strength, mobility, accuracy, or destructive force, while it would also cause manufacturing delays. In many cases, also, it would entail the provision of new ammunition.[6] The plan adopted as a rule for providing hyper-velocity guns was, therefore, to reline to a smaller calibre, long guns—such as 16-in. from the Navy or other sources, and provide them with special mountings.[7] Messrs. Beardmore designed a hyper-

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[1] D.G.M. D/G/1601.

[2] Twelve guns and cradles were also borrowed from the Navy in July, 1916.

[3] It was proposed also to use certain big guns under manufacture for foreign Governments.

[4] Vol. X, Part II, Chap. II; Vol. X., Part III, Chap. III.

[5] The rifling of the gun was another element affecting its range.

[6] D.M.R.S. 535 II.

[7] In June, 1918, an E.O.C. design of semi-mobile mounting was approved for 12-in. and other guns lined to lesser calibre. (D.G.M. D/G/0266.)

velocity 10-in. gun, but it was not accepted, largely because the mounting would have suited only that particular type of gun, and a pattern was needed which would take all hyper-velocity guns. Messrs. Vickers designed a mounting for a 16-in. gun, but it was rejected owing to its huge weight of 167½ tons.[1] The British designers, of course, had to face the special problem of evolving a hyper-velocity equipment, light enough to be disembarked in France and used on the French railways.

Difficulties of design were not insuperable, but the ultimate value of these long range guns was dubious, they would take a long time to make and would wear out very quickly. Bombardment at ultra-long ranges seemed hardly worth while, since firing was bound to be very inaccurate[2] and it seemed probable that bombing aeroplanes would serve the purpose better. At the time of the Armistice this question had not been put to the test.

The general increase of range during the war may be illustrated by considering certain types. The original range of the 60-pdr. gun was about 10,300 yds. With a different shell 12,300 yds. was reached and at the end of the war a new type (Mark IV) had just been completed, which was designed to give a range of 15,000 yds. The 6-in. 30-cwt. howitzer had only 6,000 yds range; the 26-cwt. type introduced in 1915, had 10,000 yds. At the date of the Armistice, shell which would give 11,600 yds. were in process of manufacture.[3] The range of the 6-in. Mark VII gun was about 17,700 yds. Mark XIX, though superior in other ways, had about 700 yds. less range, but it was hoped that 18,000 yds. would be reached with 4 c.r.h. shell.

The 9·2-in. howitzer, Mark I, had a range of about 10,400 yds. Mark II, with an improved shell, could reach 12,700 yds. The original 9·2-in. guns, old patterns taken from coast defence, had a range of 21,000 yds. Marks X[4] and XIII had the same range, but that of Mark XIV was estimated at 26,000 yds.

Early patterns of the 12-in. howitzer had a range of 11,000 yds., which was afterwards increased to 14,500 yds. Messrs. Armstrong's 17 calibre pattern was designed to give 15,000 yds. The 12-in. gun on railway mounting gave about 27,000 yds. range,[5] and steps were taken to increase this to over 30,000 yds.

VI. Other Modifications in Design.

(a) 18-PDR. GUN.

In addition to the improvements in this equipment which have already been mentioned,[6] there were a few minor changes. Messrs. Vickers designed an alteration to the firing gear in 1916. The rubbers connected with the system of packings were modified early in

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[1] D.G.M. D/G/0266.

[2] Light shell fired at very high elevations suffered much from deflection by the wind. This was observed of the shell fired during the bombardment of Paris.

[3] HIST. REC./R/1000/110.

[4] Mark X on an improved railway mounting could give 26,000 yards. (General Bingham.)

[5] D.G.M. D/G/073.

[6] *See* above, p. 47.

1917, and a Royal Gun Factory design for strengthening the lugs of the breech mechanism was approved in August, 1917. A steel firing platform was put forward in March, 1918, and was thought likely to be very useful for anti-tank work.

Early marks of the 18-pdr. were rather unsteady, and from September, 1914 onwards, attempts were made to remove this defect, especially towards the end of 1917, and the equipment (Mark IV gun on Mark III carriage) in use at the front for the last two months of the war proved much more satisfactory. The gun was supported on its cradle for the whole length of recoil, and was therefore very steady in firing. This equipment had the great merit of being "foolproof," and could, when necessary, give a very high rate of fire. At one time it was proposed to mount 18-pdrs. on 4·5-in. howitzer carriages as a temporary arrangement, but the project was not carried into effect, largely because it was thought the composite equipment would be unsteady.[1]

The life of the 18-pdr. worked out at something between 15,000 and 18,000 rounds, provided the rate of fire remained at about four rounds per minute. Though capable of much more rapid fire, the gun wore out sooner if this rate of four rounds per minute were exceeded frequently.

(*b*) 4·5-IN. HOWITZER.

This weapon was replacing the 5-in. howitzer before 1914. It stood the test of the war remarkably well, undergoing fewer changes than any other equipment. The only defect in the howitzer as originally designed was a weakness in part of the breech ring, and this trouble was overcome. In 1917 a new design was brought out, incorporating a system of air recuperation. As with all equipments, the course of the war brought a demand for a longer range than the original 7,200 yards, and at the end of the war a longer range type was being made. The life of the howitzer exceeded estimates, and by October, 1916, there had been no condemnations for wear or scoring.

(*c*) 60-PDR. GUN.

The 60-pdr., like the 18-pdr. and the 6-in. gun, was considered particularly liable to wear. Its life was about 5,000 rounds with full charges. The Mark I cradle was very difficult to make, and the Mark II, an inferior design, was used mainly in order to overcome supply difficulties. The Mark II equipment was unpopular owing to its weight in draught, being one ton heavier than Mark I and in June, 1916, Sir Douglas Haig asked for a reversion to the Mark I type. Supply considerations made this impossible, but the carriage and limber were subsequently modified so that the gun could be drawn back for travelling, thus lightening the wheels and axles and so reducing the weight by 9 cwt. This modification was applicable to carriages in the field as well as those under manufacture.

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[1] HIST. REC./R/1200/54.

Other modifications included a brake designed by Messrs. Armstrong for the Mark II carriage, approved in January, 1917; a Woolwich design of cradle adopted in February, 1917; a device included in the sight carrier to compensate automatically for the loss of muzzle velocity at all ranges; and a new firing mechanism, the last being approved in March, 1918. It was suspected during 1918 that the use of carbon steel instead of nickel steel was unsatisfactory, and in June arrangements were made to revert to nickel steel as soon as possible. By the time of the Armistice a new type was under manufacture. This pattern, Mark IV, fitted with a box trail, had the merit of being "foolproof" and steady, and had also an increased range. The equipment was simply the 18-pdr. Mark IV on Mark III carriage reproduced on a larger scale.

(d) 6-IN. HOWITZER.

The original 30-cwt. type of 6-in. howitzer was a useful weapon, with a life of about 5,000 rounds. Traction was originally by horses, but later motor transport was used for most of these howitzers. A more mobile and longer ranging pattern was required after a time, and the 26-cwt. type, which was designed in 1915 and introduced in 1916, proved far superior to the earlier howitzer.

Various modifications were introduced, usually at the suggestion of Messrs. Vickers, the designers of the original pattern. At the end of 1915 the firm proposed to modify the sighting gear and to construct the carriage for faster transit than the six miles per hour for which it had been designed, while a year later a method of strengthening the spade and a design of cast iron blocks to support the front transom were approved.

The breech mechanism was altered in 1916 to prevent scoring in the cam groove, and in March, 1917, the breech ring was modified.[1] The trails of the travelling carriage were strengthened, and a platform was designed by Messrs. Vickers. This was at first too weak, and even when strengthened was not quite satisfactory, but platforms made of steel instead of wood were under construction in February, 1918.

General Headquarters valued the 6-in. howitzer highly, but considered its range too short and its power inadequate against modern emplacements.[2]

(e) 6-IN. GUN.

The first 6-in. guns were taken from coast defences and used on improvised railway mountings made by Woolwich and the railway companies. The chief defects of the 6-in. Mark VII gun were heaviness and shortness of life, the latter being only about 1,200 rounds. The 35 calibre type was designed by Messrs. Vickers, and approved in July 1916.[3] The gun was at first mounted on an 8-in. howitzer carriage, and the equipment was considerably lighter than Mark VII and had almost as long a range. Mark XIX appeared in the field in March, 1917, and soon became an extremely popular weapon, the gun and carriage together weighing just over 10 tons only.

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[1] (Printed) *Weekly Report*, No. 83, IX (10/3/17).
[2] D.M.R.S. 404.
[3] D.G.M.D/G/487.

Certain changes were made in this type, the rear beams of the firing platform, for instance, being strengthened. Its great fault was its very short life, the rate of wear far exceeding the capacity for re-lining and new production.

(*f*) 8-in. Howitzer.

The 8-in. howitzer was made originally by a conversion from the 6-in. gun, which was shortened, the chamber being enlarged.

The early types, Marks I to V, had a range of 10,000 yds., and did good work but were cumbersome, and recoiled only on scotches. In August, 1915, Messrs. Vickers produced a design firing from its own carriage (Mark VI). This equipment, which was very much like the 6-in. howitzer, was easier to make than the 9·2-in. howitzer.[1] The carriage was capable of 50° elevation, and 4° traverse either way, and had hydro-pneumatic recuperator and hydraulic buffer. The equipment could travel at the rate of 12 miles per hour with motor tractor.

Some trouble was experienced with the trail, which at high elevations dug itself into soft ground, the wheels also sinking, while on very hard ground a cake of earth would become pressed between the flanges, and the spade, unable to bed itself, would make a furrow.[2] Thus the recoil system would not work satisfactorily, and the shooting was inaccurate, though the gun was reported steady and the rate of fire good. A commission sent to France to investigate these difficulties recommended the use of a removable spade, so that the howitzer could be fired from a platform with recoil scotches. In January, 1917, Messrs. Vickers' design of firing platform was accepted, and in February the use of scotches was approved.

Mark VII, which was designed by Messrs. Vickers to meet the demand for a longer range howitzer, was of 17·3 calibre. It was introduced in July, 1917, and was unsatisfactory at first, in spite of its range, which exceeded that of Mark VI by 200 yards. Its life proved extremely short, and a number of guns were condemned after a very short time for cracked inner A tubes. Mark VIII, designed in 1916, was a strengthened form of Mark VII, being 5-cwt. heavier, and had a slightly longer range.[3]

(*g*) 9·2-in. Howitzer.

The 9·2-in. howitzer, which had been approved just before the war, did very good work as a counter-battery weapon.[4] Mark I. was of 13·24 calibre and wire construction, and could be fired between 15° and 55° elevation. Its life was about 6,000 rounds. Mark II, designed in 1916 to meet the demand for longer range, was 17·3 calibre in length, and a good deal heavier than Mark I.

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[1] C.R. 4419.

[2] D.G.M.D/G/1029. The piston rod also struck the ground at high elevations. In 1916, Messrs. Vickers designed a modification to the trail so that the carriage could take the 6-in. 35 calibre gun also. (D.D.G.(D.)223.)

[3] D.D.G.(D.) 140.

[4] D.G.M.D/G/160.

The recoil of the equipment was excessive, and, in 1916, modifications were designed to correct this fault. In November, 1917, the recoil system was further improved by the addition of a recoil indicator and tell-tale for the cut-off gear.[1] The anti-friction washer gave trouble, the steel ring breaking and causing violent recoil and damage to the whole recuperator system. Plain steel washers, without the oil groove, were considered better.

(*h*) 9·2-IN. GUN.

The earlier Marks of this type were old pattern guns taken from coast defence and mounted on railway mountings. The old pattern had only 10° traverse right and left, and could not be re-lined. In September, 1916, the equipment, comprising a Mark III gun on railway mounting, was modified to give 45° elevation.

The supply of Mark X consisted partly of coast defence weapons, though some new guns were made. In August, 1918, two new designs of Mark X were approved for coast defence purposes.[2] In the summer of 1916 Messrs. Armstrong designed a railway mounting capable of all round fire, 30° elevation, and of being anchored along the rails, to take Mark X and Mark XIV guns. The latter type, a 45 calibre gun originally made for a foreign power, was supplied by Messrs. Vickers from stock, the first equipment being tried in September, 1917.

Mark XIII was a 35 calibre gun on railway mounting, with all round traverse, designed by Messrs. Armstrong in the summer of 1916, to obtain better mobility and accuracy at long range, in which respects Mark X was deficient. The equipment provided for 40° elevation. Run-out springs made air recuperation unnecessary. The truck was fitted with swinging arms ending in spades designed to be buried in the ground. The gun recoiled three feet when firing at the horizontal. This equipment was found to fire satisfactorily at right angles to the railway track, and to be accurate at medium range and very satisfactory at long range.

(*i*) 12-IN. HOWITZER.

Early in the war a committee was appointed to consider the question of siege artillery, and the 12-in. howitzer was one of the types recommended by the committee.[3] Although classed as "very heavy," the 12-in. howitzer was used on mobile mountings.

Mark I, II and IV were designed by Messrs. Vickers for road mountings, but Marks I and II were also used with rail mountings. The latter were made by Messrs. Armstrong, who designed the Mark III and Mark V guns, for which road transport was not used at all. The railway type, though unpopular at first, had great advantages when the roads behind the front were congested. It was also almost invisible from an aeroplane.[4] In August, 1918, a special engine was designed to take the howitzer round curves, where a railway engine would be unsuitable.

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[1] D.G.M.D/G/014.

[2] Mark X was sometimes used on Mark III railway mounting.

[3] *See* Vol. I., Part I.

[4] At the end of 1915 the War Office asked for one-third of the total to be road equipments and two-thirds to be of the rail type.

Mark I, a 12 calibre weapon, similar in many ways to the 9·2-in. howitzer, received great praise from G.H.Q. in November, 1916. Mark II was not at first entirely satisfactory, but in September, 1917, its behaviour was reported to have improved, owing to the elimination of defects, increased experience in its use and avoidance of excessive fire.[1] It was designed for use between 40° and 65° elevation, and was unsatisfactory if fired at a lower angle. For manufacturing reasons, Mark II was sometimes used on Mark III mountings.[2] Mark III, approved in February, 1916, was of 17·3 calibre, and the equipment had spades to give an all round traverse. Mark IV was extraordinarily accurate in fire, the average error at very long range being only 10 yards.

A great fault of the 12-in. howitzer was its extremely short life. This had been estimated by the Ordnance Committee at 4,000 rounds, but G.H.Q. reported it at the end of 1916 as more likely to be about 1,250 rounds, with full charges.[3] It was hoped that alterations to the driving band of shell would improve this state of affairs.

(*j*) 12-in. Gun.

This gun was really a naval type, but two guns were handed over by the Admiralty and sent to France on railway mountings early in 1916. Elevation could reach 30°, but only one degree of traverse was possible each way. Recoil at degrees below 16 reached 22-ft., and was 16-ft. at 30°. At the end of the year approval was given to a Vickers design of gun (Mark IX) with 35½° elevation on railway mounting. In February, 1917, there was some discussion as to the desirability of supplying blocks to check recoil. Much labour was spent in running the gun up after each round, an engine being needed for this purpose.

Early in 1918, Messrs. Armstrong designed an adapter to enable the 12-in. gun to be used on a 14-in. railway mounting and in June a design was approved of semi-mobile mounting for long range guns of 12-in. and larger size.

(*k*) 14-in. Gun.

These guns had been made for a foreign power. A railway mounting to give 40° elevation and 2° traverse was designed by Messrs. Armstrong Whitworth in 1916. An air compressor was designed by the same firm.

(*l*) 15-in. Howitzer.

This type was used by the Royal Marine Artillery and had a range of 10,000 yds. The Coventry Ordnance Works designed a mounting. At the end of 1916, G.H.Q. asked that no more new howitzers should be produced, but repair should continue. The life of the howitzer was estimated by G.H.Q. at about 4,000 rounds,[4] but the Director-General of Munitions Design was inclined to think 3,500 a more exact figure. In January, 1917, a design of a 17-calibre howitzer on a railway mounting was brought forward but abandoned owing to the success achieved with the 12-in. howitzer.

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[1] D.G.M.D./G./1601.

[2] In November, 1916, Vickers received an order to adapt Mark II to be fired from a concrete foundation. (D.D.G.(D.) 144/6.)

[3] D.G.M.D/G/1601.

[4] D.G.M.D/G/937.

CHAPTER V.

THE MANUFACTURE AND REPAIR OF GUNS.

I. Organisation of the Gun Department.

When the Ministry of Munitions was established in June, 1915, a section, under Major (later Colonel) W. C. Symon, was formed in Deputy Director-General (C)'s division of the Munitions Supply Department to deal with the supply of guns and equipment. In July, 1915, the section was placed under a newly appointed Deputy Director-General (D)—Mr. (later Sir Charles) Ellis—Colonel Symon being responsible for field guns and equipment, and Captain Ramsden for artillery stores and spares.

This organisation underwent little change. Until October, 1916, the Gun Section formed part of the Munitions Supply Department; it then became part of an Ordnance Supply Department. In February, 1917, in order to expedite gun repair and to utilise surplus shell capacity, Sir Glynn West became responsible for the supply of guns, as Director-General of Shell and Gun Manufacture, and eventually the department became part of his Group, G, under the Munitions Council, which in its turn was amalgamated with the group of departments under Sir James Stevenson in January, 1918, and became Group O.

II. Chief Processes of Gun Manufacture.

The production of ordnance demands a very high quality in management and engineering skill, and a high degree of skilled labour applied to material of a very high quality. This is illustrated by a brief review of the main processes of manufacture.

A gun has been described as a tube "intended to stand a given internal pressure, and to throw a projectile which shall produce certain effects at given distances."[1] The designer of a gun has to consider the different stresses set up by firing at different sections of the tube, and to arrange that each section is strong enough to withstand the corresponding stress. The material of which the gun is made must be such as to permit the firing of a large number of rounds without undue erosion. Moreover, the strength must be disposed in the most economical way, to keep the weight of the gun as low as possible. If a gun were made from a single hollow cylinder, it could withstand comparatively little internal stress, for the strength of a cylinder does not increase uniformly with its thickness, and can never exceed the elastic limit of the material. A gun intended to withstand high chamber pressure is therefore made by a process

[1] *Ministry of Munitions Journal*, February, 1918.

of "building-up." Instead of one cylinder there are various layers of steel[1] or steel and wire, each layer being made to take its share of the stress caused when the gun is fired. A combination of steel and wire gives greater radial strength, for the same weight, than construction by steel alone.

A normal gun or howitzer consists of an inner tube called an "A tube," over the front end of which a muzzle stop ring is shrunk. If wire construction is used, the wire is wound over the exterior of the A tube from the breech end to the stop ring. The jacket is shrunk over the A tube, wire and stop ring, and secured longitudinally by the breech bush which is screwed into the rear end of the jacket, and screwed internally to take the breech screw. The breech ring prepared to take the breech mechanism, is screwed and shrunk on to the rear end of the jacket.

The exterior of the A tube is rough turned, and after hardening,[2] tempering and testing, a second rough turning and rough boring takes place. The tube is then finish bored, and turned for wire seating. The muzzle stop ring, previously machined, is shrunk on. The next operation is winding the wire, which is usually 0·25-in. by 0·06-in. in section, and is tested before use. When wound over the A tube, the end of the wire is hammered into a prepared recess. The wire is then turned for the jacket seating, and the stop ring finish-turned. The heated jacket is shrunk on to the A tube and cooled by water rings. In the case of very long guns, when the inner tube has several steps or shoulders, the upper portions of the outer tube are kept hot, one method being the use of gas-rings.

When the jacket has been shrunk on, the bore is tested for concentricity. The inner tube is then finish bored to plan size. The chamber is rough and finish bored, the breech end of the jacket bored and screwed to take the breech bush, the cone-seating for the obturator is bored, and the breech bush is machined and screwed into the gun body. The next operation is that of rifling, cutting a spiral groove in the interior of the innermost tube. The twist of the spiral determines the spin and velocity of the shell. After rifling, the bore is lapped, to remove any burrs and to give a polish to the lands. The exterior is finish-turned, and the breech ring built on. The body is finish planed, and the piston hole and other holes are bored and the guides finish-milled. The gun or howitzer is next adjusted to suit a model breech mechanism, thus securing interchangeability.

A careful inspection is made before proof. The dimensions of the bore are tested, and an impression of the sifting made and examined. After further testing, a model breech mechanism is swung into the breech opening, and the obturator cone-seating cut to a gauge attached

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[1] The steel might be either of the carbon, nickel or nickel-chrome class. (Hist. Rec./R/1141/42.)

[2] Until about 1916, water-hardening of gun tubes was thought to be likely to cause cracks and defects, but in some ways it proved better than oil-hardening, as it increased the yield point and the maximum stress and the percentage ratio of the yield to the maximum stress, and it was hoped that thus the number of guns failing through stretching and expansion of the A tubes might be reduced.

to the model breech screw. The clinometer plane is cut, and in the case of guns, tests are made to ascertain whether there is any droop or bend in the axis of the bore. The profile and diameters of the exterior and the axis lines are checked, and the gun or howitzer is then ready for proof.

By the spring of 1918, most heavy guns and howitzers, and many medium guns, were being made with inner A tubes, which were introduced to facilitate repair of eroded guns. An inner A tube is finished to slightly larger dimensions than the interior of the A tube into which it is forced. Stepped shoulders are made on the exterior of the inner A tube and the interior of the A tube, and a series of narrow and shallow grooves are cut on the internal surface of the A tube to give it a still firmer grip on the inner A tube. Finally, the inner A tube is forced into the A tube by " tripping "—pressure from a falling weight.

III. Steps taken to increase Home Supplies.

(a) EXTENSIONS TO ARMAMENT FIRMS.

The contracts placed by the War Office during the first year of the war as a rule contained some provision for financial assistance to firms to enable them to provide the new buildings and plant by means of which they hoped to meet the heavy demands made on them. The policy of the Ministry, also, was to help the firms in every possible way to make the large expansion required of them. At the conferences in July, 1915, a greatly increased output was arranged for; the following table shows the provisional allocation of new gun orders to contractors suggested by Mr. Ellis and sanctioned by Mr. Lloyd George on 30 July.[1]

Type.	Armstrong.	Vickers	Beardmore.	Coventry Ordnance Works.	Ordnance Factory.	Bethlehem.	Total.
18-pdr.	46	46	90	—	—	400[2]	582
60-pdr.[3]	400	—	—	—	180	—	580
4·5-in. Howitzer ..	—	—	—	461	176 Equipments + 12 Guns		649
6-in. Howitzer ..	—	338	120	—	—	—	458
8-in. Howitzer ..	—	—	—	—	48	—	48
				To convert if guns available.			
9·2-in. Howitzer ..	—	120	36[4]	—	—	—	156
12-in. Howitzer ..	16[5]	—	—	—	—	—	16

Orders for 41 60-pdrs. and 126 9·2-in. howitzers remained to be placed, and it was suggested that orders for some of the latter might be given to Messrs. Armstrong.

[1] C.R. 4419.
[2] Already sanctioned by Ministry.
[3] Leaving 41 still to be placed.
[4] Waiting instructions as to type of mounting.
[5] On 18 September 52 8-in. were ordered in lieu of the 36 9·2-in. (D.D.G.(D.) 221).

On 5 and 6 August there were meetings with the gun-makers to discuss this proposed allocation of orders and settle questions of price, capital expenditure and contract conditions as far as possible. Each of the firms promised to submit details of the capital expenditure and of the amount of skilled labour required to carry out the additional contracts. The details as to the financial arrangements were left for further discussion. In all cases the money required for the extensions was to be found by the Government, but most of the firms preferred to pay interest on the capital so advanced by the Government and retain the new plant at the end of the war. The price of the guns was left open until the firms could give some details of the cost of manufacture. It was proposed that the Government should have power to cancel its orders at any time by assuming responsibility for the cost of incomplete guns and accessories, contracts for material and so on.

Expenditure on extensions to the works of armament firms sanctioned in July and August, 1915, amounted to over £2,300,000,[1] and further large extensions had been authorised by the end of the year. Messrs. Armstrong extended their works at Elswick and Openshaw and took over new shops at Gateshead and York. Messrs. Beardmore made extensions at Dalmuir and Parkshead, including large shops for 8-in. howitzers and carriages. Messrs. Vickers' works at Sheffield, Barrow and Erith were all enlarged, the most important extensions being for 9·2-in. howitzers. A comparatively small expenditure (£280,000) by the Coventry Ordnance Works was also sanctioned.

Further developments took place in 1916. In the summer large extensions by all four firms were sanctioned, in connection with the increased repair programme, while Messrs. Vickers also built new shops at Sheffield for 18-pdrs., 6-in. howitzers and 6-in. guns, and the Coventry Ordnance Works for 6-in. guns and 4·5-in. howitzers. In the autumn a good deal of plant had to be turned over to naval work, and new plant for making breech mechanisms was installed at Woolwich and by Messrs. Armstrong, Vickers and the Coventry Ordnance Works. Extensions costing £1,100,000 for naval and repair work at Woolwich were also sanctioned.[2] In November, the Ministry announced that Woolwich and the armament firms would be required, in addition to repair work, to continue the manufacture of certain natures at their maximum capacity on the conclusion of existing contracts. Further extensions were considered necessary, and an estimated expenditure of £988,000 was sanctioned, £400,000 of which was for additions at Woolwich. An extension to a steel foundry at Darlington was estimated at a further £350,000.

Besides extending their existing works the armament firms set up shops in new districts: for instance, Messrs. Vickers opened a casting foundry at Ipswich and Messrs. Armstrong metal works at Blaydon-on-Tyne.

(b) Relations with the Principal Contractors.

In the early part of the war Woolwich and the armament firms were allocated the classes of work which they could best undertake, and were given continuation orders when the completion of their existing

[1] Hist. Rec./H/1200/6. [2] D.M.R.S. 404.

contracts was in sight.[1] In November, 1916, however, owing to the pressing need for guns of nearly all types, a rather different method was adopted. Woolwich and the four armament firms were told to continue production of certain natures at their maximum capacity until further notice.[2] This decision gave a great stimulus to production, while the interests of economy were served by the magnitude of the orders.

The original policy was to obtain each type of gun from two sources, but, with the increasing demand for 6-in. guns and 8-in. howitzers, this method had to be abandoned, and ultimately all four firms made these two natures.[3] The principle of differentiation, however, did not disappear altogether;[4] for instance, in August, 1917, Coventry Ordnance Works gave up the 6-in. howitzer and concentrated on 4·5-in. howitzers, of which they were the only British producers, except Woolwich.[5]

Ultimately, the unit of manufacture tended to be a group of firms in a certain area, supervised by one of the armament firms; Messrs. Vickers, for instance, evolved a very complete system of controlling sub-contractors in the Manchester area. As far as possible all the work involved in producing a complete equipment was allotted to firms in the same district. This policy of co-operative manufacture within a certain area had the advantage of permitting extensive sub-division of labour, while it minimised delay in the transport of components and the assembly of complete equipments.

The efforts made by the Ministry to supervise manufacture by its four principal contractors may be outlined here. By September, 1915, a weekly progress report had been instituted, and the director of the Gun Department took action to remove any causes of delay revealed by the report. By January, 1916, resident supervisors had been sent to Messrs. Armstrong Whitworth and Messrs. Vickers, and some of their sub-contractors, while a similar appointment was to be made at Messrs. Beardmore's. In June, 1916, arrangements were made for weekly meetings to be attended by representatives of the armament firms, to discuss suggestions for improving output, and settle minor points of inspection and specification.[6]

A very important part of the organising duties of the Ministry consisted in co-ordinating the work of different firms. The main components of an equipment were often obtained from different manufacturers, and care was needed to correlate the supply of parts. Guns and carriages had also to be produced at the same rate, so that they might be proved together. A similar problem was the co-ordination of the work of overseas shops which did repairs and produced spare parts.

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[1] D.D.G.(D.) 141/1.
[2] In February, 1917, firms were told to inform the Ministry when further orders were required.
[3] HIST. REC./H/1200/6.
[4] Efforts were made to employ one firm on one type of forging.
[5] One order was placed in America.
[6] D.D.G.(D.) 144.

(c) THE INTRODUCTION OF NEW FIRMS.

In the later years of the war a considerable number of engineering firms were employed on gun work as sub-contractors for components, carriages, etc., to the armament firms and Woolwich. These firms were supervised to a considerable extent by the main contractor; they were also inspected by the Ministry of Munitions, and received help in obtaining material and labour. The Ministry was often called upon to exercise pressure on sub-contractors who failed to keep delivery promises, or to see that priority was given to the most urgent work where a firm held more than one sub-contract. In June, 1916, it was proposed that the armament firms should state their requirements, when the Ministry would try to apportion the work among sub-contractors, and by degrees a record was compiled of firms suitable as sub-contractors whose names were suggested to the armament firms.[1]

In course of time it became evident that Woolwich and the four armament firms even with the assistance of sub-contractors, could not keep pace with the demand for gun equipments and the circle of manufacturers on ordnance work grew steadily wider. Carriage-limbers, ammunition-wagons and wagon-limbers had always been made very largely by sub-contractors, and eventually the Ministry took away most of this work from the four gun-making firms, and placed contracts direct with makers such as the Metropolitan Carriage Wagon and Finance Company, Messrs. Beyer Peacock, of Manchester, and various railway companies. Sights, except the optical portions, were also made on direct contract by various firms, such as Messrs. E. T. Moir, in 1916; ten firms who were reported to do very accurate work having been brought in by May.[2]

About the middle of 1916 new firms were recruited to make parts of guns and howitzers, and in the spring of 1917 for the supply of forgings for repair work; while in the autumn many firms—several of which had helped with gun repair work—began to make gun bodies. Thus, the British Westinghouse Electric and Manufacturing Company made 9·2-in. howitzer bodies; the Austin Motor Company, 4·5-in. howitzer bodies; Messrs. Dick Kerr & Company, Mather & Platt, and the Rees Roturbo Manufacturing Company, bodies for the 6-in. 26-cwt. howitzer; while Messrs. Harper, Sons & Bean, made 60-pdr. guns. Assembling of 9·2-in. howitzer equipments was carried out by the Cunard Steamship Company. Orders for rough borings were offered to three Sheffield firms, Messrs. John Brown, Thomas Firth and Cammel Laird, and to the Darlington Forge Company; and the capacity of various firms in the London area was examined.[3]

A radical change of policy, involving the repair and later the manufacture of guns in national shell-making factories, dates from the early part of 1917, when several National Projectile Factories took up gun repair in addition to their ordinary work. Later, three of these factories were definitely turned over to gun work and became known as National Ordnance Factories. Thus the National Projectile Factory at Nottingham managed by Messrs. Cammel Laird, was turned

[1] D.D.G.(D.)141; 141/2. [2] HIST. REC./R/1200/55. [3] D.D.G.(D.)141/2.

over, after a period of repair work, to the manufacture of 18-pdrs.[1] and 6-in. Mark XIX guns, and became the Nottingham Ordnance Factory.[2] Messrs. Hadfield's National Projectile Factory at Sheffield also became an Ordnance Factory and made 60-pdr. guns. The Leeds National Projectile Factory began 18-pdr. gun manufacture at the end of 1917, and developed capacity for making 200 gun bodies per month.[3]

Firms new to gun work needed more help than the four main contractors required in the provision of material, machinery and labour, partly because the lesser firms were in an inferior position for bargaining, but chiefly because they could not get good results unless the material supplied to them was of first rate quality.

(*d*) EMERGENCY METHODS OF SUPPLY.

At very critical times the Admiralty sometimes helped by allowing the postponement of work on certain naval contracts. For instance, early in 1916 it was arranged that in order to hasten production of guns for the Army, manufacture of four 9·2-in. and twelve 4-in. naval guns should be suspended together with the repair of four other guns.[4]

Guns had sometimes to be taken from coast defences, as in the autumn of 1916, when the Navy was in urgent need of guns. At other times, the Navy lent guns to the Army ; for instance in the autumn of 1917 and spring of 1918, when there was an imperative call for long range artillery. Extensions for new production or repair, or for supplies to the Allies, had sometimes to be given up to ensure an immediate increase of output to meet a temporary need. Use was also made of guns intended originally for foreign Governments such as Italy, Chile or Russia.

IV. Supplies from Abroad.

The British Army depended for its supply of guns mainly upon manufacture within the United Kingdom, and supplies from abroad were comparatively unimportant. Within the Empire, the only contribution came from India. Besides meeting many of the needs of the Indian Army and the forces in Mesopotamia, India supplied guns of various calibres to the home Government.[5]

The most important sources of gun supply apart from those in Great Britain, were found in the United States. For the first year of the war, the Bethlehem Steel Company was the only firm both capable of the work and willing to undertake it for the British Government. The Bethlehem Company was well known as a high-class firm, and was accustomed to gun manufacture. In the autumn of 1914, at an interview between Lord Kitchener and Mr. Schwab, the company's

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[1] D.D.G./G.M./140. [2] C.G.M. 387/3.

[3] D.D.G./G.M./504/14 ; C.G.M. 357/Q. A fourth National Ordnance Factory for the manufacture of a new automatic gun (1½-pdr.) for the Air Force, was established at New Basford, near Nottingham, in 1918. For an account of this, and for further details of the other National Ordnance Factories, see Vol. VIII, Part II.

[4] HIST. REC./R/1200/22. [5] *See* Vol. II, Part V.

representative in London, it was arranged that all the Bethlehem capacity should be offered to the British War Office and Admiralty, and that the company would not sell any war material without first offering it to Great Britain.[1]

The first order given to Bethlehem was placed in November, 1914, and covered the supply of 200 18-pdr. equipments. Delivery was expected by the end of June, 1915, but was far behind time. Only six equipments had been despatched by August, and the order was not complete until March, 1916. Meanwhile, in April, 1915, the company asked for further orders. Special shops had been built for 18-pdr. manufacture, and if the British Government did not place more orders, the capacity would be turned over to execute orders coming from another source. The British authorities thought it desirable to place a continuation order so as to hasten deliveries if possible, but nothing was settled until the end of June. Contracts were then placed for 50 18-pdrs. for delivery during December, 1915, and 100 13-pdrs. to be delivered in the first quarter of 1916. These anticipations, however, were not realised. The 18-pdrs. were delayed until March, 1916, delivery being completed in June, while the 13-pdrs. were delivered from May to December, 1916. A fire at the Bethlehem Company's works in November, 1915, destroyed or damaged 18-pdr. equipments and machinery, particularly carriage machinery. Thus the company's production was hampered for a long time.[2]

Soon after the formation of the Ministry of Munitions, further orders were given to the Bethlehem Company, a contract for 400 18-pdrs. being placed in August, 1915. Deliveries were to be completed in June, 1916, but again the estimates were too sanguine, and the full number had not been delivered by June, 1917.

In January, 1917, the firm accepted another order for as many 18-pdrs. up to 250 as could be produced by the end of 1917. They could, however, only promise 200 within the stipulated time.

Immediately after its formation, as has been seen, the Ministry took steps to ascertain whether any American firms could supply heavy howitzers. The Bethlehem Company submitted proposals which were not received with much favour for financial reasons, but owing to the urgent need for supplies a contract was placed in September, for 150 9·2-in. howitzer equipments. This contract also was seriously in arrears, 3 equipments being forthcoming in March, 1917, when all were due. A contract of October, 1915, for 150 4·5-in. howitzers was equally disappointing. Owing in part to the destruction of 4·5-in. machinery in the fire in November, 1915, no deliveries were made until January, 1917.

Meanwhile, the capacity of another American firm had become available for the Ministry. The Midvale Steel Company, in which there was a strong pro-German interest, had at first refused to manufacture for the Allies, but in the summer of 1915, a change of ownership took place, the company being purchased by a syndicate which was willing to come to an agreement with the British Government. In November a contract was under negotiation for 200 6-in. howitzer and

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[1] Hist. Rec./H/1141/6. [2] It was suspected that the fire was due to foul play.

200 8-in. howitzer equipments. At this time Russia stood badly in need of howitzers, and on 3 December it was agreed that the output from the Midvale order should be transferred to her. The 6-in. order was not immediately proceeded with, but after much discussion as to price, an order for 100 8-in. equipments was placed in April, 1916. Later on, 120 6-in. 26-cwt. equipments were also ordered on behalf of Russia.

The methods of the Ministry in helping British contractors were applied, as far as possible, to its dealings with American firms. Advances were made towards the cost of plant, and men from both Bethlehem and Midvale visited British shops to see the process of manufacture. British inspectors in America performed their work so well that the Bethlehem Company gave the helpfulness of the inspection authorities as one of its reasons for preferring British contracts to any others.

With all these advantages, there was serious delay in deliveries from American firms, and the contracts were also unsatisfactory on financial grounds. The Bethlehem and Midvale Companies for instance would not accept a break clause. The embargo clause, which had provided that if the United States Government forbade the export of guns, the contractor would refund any sums paid by the British Government in advance for the guns ordered, was modified in Bethlehem's interest when the contract of July, 1915, for 18-pdrs., was placed.[1]

When negotiations with the Midvale Company were in progress the British Government were asked to make a large advance for extensions, the output from which would be allocated to them for five years, after which time a proportion of the sum advanced would be refunded. This scheme was not agreed to and the contract ultimately concluded was on a smaller scale than that originally contemplated.

In the early days of the war close bargains could not be driven and there was little evidence by which to estimate a " fair price." American quotations were much higher than those of British firms, and the British Government had also to bear the cost and risk of transport by sea and the loss due to an adverse exchange ; but there was frequently no choice between the contractors' terms and the abandonment of much needed supplies. Thus the Ministry were obliged to agree to pay the same price for 18-pdr. and 13-pdr. carriages on the Bethlehem contracts of June and July, 1915, although the 13-pdr. carriages was lighter in metal, and Messrs. Armstrong made a considerable difference between the two prices. Similarly, the price asked by Bethlehem for a 4·5-in. howitzer equipment ($13.688) was considered much too high, while the price quoted for bar sights and dial sight carriers for these howitzers was three times that current in England, but attempts to secure a reduction were unavailing. British armament makers always reduced their prices after the first orders, but American firms did not, although their expenses must have diminished in exactly the same way.

[1] In March, 1917, owing to the urgent need for 18-pdrs., the Ministry ceased discussion of the embargo and break clauses, but arranged that no deliveries should be accepted after the end of the year, and that 5 per cent. should be deducted from the price of every gun delivered late.

It was only in the case of the earlier orders, however, that the shortage of supplies made it necessary to place orders in America regardless of financial considerations. Home resources developed rapidly, and by 1917 it was possible to reject American terms if they were considered too high. Thus, when in January, 1917, the Bethlehem Company quoted $600 each for 18-pdr. breech mechanisms, it was decided, after comparison with Woolwich estimates, to place the order in England. The adverse exchange was a strong reason for avoiding American contracts, while the reduction of price by British firms for continuation orders and the control of profits under the Munitions of War Act made the Ministry anxious to obtain their supplies from home as far as possible, an additional reason being the delays in delivery on American orders.

V. Supply of the Main Types.[1]

(a) 18-pdr. Gun.

Before the formation of the Ministry of Munitions, the War Office ordered 18-pdrs. from the Ordnance Factories, Messrs. Armstrong, Vickers and Beardmore, and the Bethlehem Steel Company. The first orders were arranged immediately war broke out, and by the end of August, Woolwich had promised 68 equipments and Messrs. Vickers and Armstrong 78 each. The orders were increased during the following weeks, and further big developments were arranged at a conference with gunmakers in the middle of October. By the end of that month Woolwich had promised 168 complete equipments, Messrs. Vickers 1,010, Messrs. Armstrong 1,000, and Messrs. Beardmore 200. Delivery of the whole number was hoped for by the summer of 1915, and at the end of 1914 arrangements were made for the continuation of output on the completion of existing orders; Messrs. Armstrong and Vickers agreeing to undertake 450 each and Messrs. Beardmore 70. In November, 1914, also a contract for 200 complete equipments was concluded with the Bethlehem Steel Company, and a further order was negotiated in 1915.

Although the deliveries on these early orders were seriously behindhand when the Ministry was established, the large expansion of capacity arranged for by the War Office in time gave a satisfactory output, and the War Office contractors remained throughout the principal sources of supply. The largest orders were given to Messrs. Armstrong and Messrs. Vickers; for instance, during six months in 1916, 570 guns were ordered from Messrs. Armstrong; and between 29 August, 1916, and 23 February, 1917, Messrs. Vickers received orders for 724 guns.[2]

By 1917, however, additional capacity was required and new British firms were turned on to 18-pdr. work. In May, 1917, a shell shop at Messrs. Hick Hargreave's works at Bolton was converted and extended for making 18-pdr. air recuperators, while the National

[1] For anti-aircraft guns *see* Vol. X, Part VI, and for tank guns Vol. XII, Part III.

[2] Including 198 originally ordered by Canada in May and November, 1914.

Ordnance Factories at Nottingham and Leeds made gun bodies in 1918.[1] Cradles for 18-pdr. carriages were ordered from the Linotype and Machinery Company at the end of 1917, while mechanisms were ordered in May and July, 1918, from Messrs. T. Glover & Company, and the Pelabon Works respectively.

As with all natures, there were periods of special demand for the 18-pdr. gun, and times when its production had to give way to other requirements. In August, 1916, inquiries were made as to whether additional orders would help to ensure supply during the early months of 1917.[2] Plans were considered for a large additional output from Messrs. Armstrong,[3] but the imperative need for naval guns made it necessary to abandon these proposals. It was suggested that some partly worn 18-pdrs. should be turned over to the Admiralty, as better weapons were not immediately available, but even without this extra call on supply, the 18-pdr. position was not very satisfactory at the end of 1916. Deliveries had fallen below expectations, while an abnormal number of guns had recently been lost as the result of prematures.[4]

One of the most pressing periods of demand for 18-pdrs. occurred in the early part of 1917[5] and in January the Ministry gave instructions that except by special order manufacture was not to be suspended in favour of 18-pdr. guns for the Navy. In February it was estimated that if the whole ration of ammunition were fired, expenditure would exceed supply by 70 guns. At a conference in March representatives of G.H.Q. urged that more 18-pdrs. must be produced even at the expense of 8-in. howitzers, and that guns must be supplied even if carriages and mechanisms were not forthcoming. The need was still felt keenly in May. Another period of very urgent demand—principally, in this case, for breech mechanisms—occurred during the German offensive in the spring of 1918. At this time steps were taken to organise groups of firms working under local Boards of Management for co-operative manufacture of mechanisms, Belfast in particular being considered a very suitable centre for this work.[6]

(*b*) 60-PDR. GUN.

The first trade orders for 60-pdr. guns were arranged at the beginning of October, 1914, when the War Office ordered 36 complete equipments from Messrs. Armstrong and the same number from Messrs. Vickers. Arrangements for production at Woolwich had already been made, and by the middle of October, 36 had been ordered from this source, a further 40 being ordered in March, 1915.

The Ministry of Munitions treated Messrs. Armstrong as the principal source of supply for this gun. In July, 1915, 400 equipments were ordered from the firm,[7] and in September a further 161. Among later orders were those of October, 1916, for 290 gun bodies;[8] of

[1] *See* above, p. 63. [2] D.D.G.(D.)141/1. [3] D.G.O.S./D/15.

[4] It was known also that a very large number of guns would need repair simultaneously. [5] D.D.G.(D.)140. [6] M.C. 723. [7] 94/G/451.

[8] 94/G/4353. The 60-pdr. was one of the natures of which, in November, 1916, Armstrong Whitworth were instructed to continue maximum production until further notice.

June 1917, for 500 bodies;[1] and of October 1918, for 140 equipments. A new shop at Elswick was erected specially for the production of the 60-pdr., and an extension at Openshaw was made partly for the same purpose. Messrs. Armstrong used Messrs. Thomas Firth, of Sheffield, as a sub-contractor for A tubes, jackets and breech rings.[2]

In the spring of 1917 additional capacity for repair and production was sought, and firms such as Messrs. Cammel Laird and Messrs. W. Somers received orders for inner A tubes for 60-pdr. repairs.[3] Messrs. Hadfields' National Projectile Factory, at Sheffield, also undertook repairs, and later started manufacture of 60-pdrs.[4]

Certain other minor firms, such as Messrs. Harper, Sons & Bean, also undertook 60-pdr. production in 1918, while carriage manufacturers included Messrs. Beyer, Peacock (Manchester), Messrs. Entwistle and Gass (Bolton), and Messrs. Kearns, Ltd. (Altrincham). Mechanisms were made by Messrs. Vickers (Sheffield).

Deliveries of 60-pdrs. were considerably delayed in the latter part of 1915 and the beginning of 1916, owing to difficulties with materials and machinery, modifications of design, failure of sub-contractors, and the shortage of certain inner tubes, for the supply of which the Ministry was responsible.[5] Again in the autumn of 1917 production by Messrs. Armstrong was diminished, owing to shortage of steel and of A tubes, which were to be supplied to the firm in order that its own steel works might concentrate on jackets.

Supplies of these guns were also wanted for Russia; and by August, 1917, 52 guns had been supplied.[6]

(c) 4·5-in. Howitzer.

The manufacture of the 4·5-in. howitzer was carried out mainly by the Coventry Ordnance Works. Orders were given to Woolwich from time to time, to the Bethlehem Steel Company in October, 1915, and to the Austin Motor Company for 1,000 howitzer bodies in the autumn of 1917, but the Coventry Ordnance Works throughout the war were recognised as the main source of supply.

At the outbreak of war deliveries of 4·5-in. howitzers were outstanding on an Ordnance Factory order and also on an order for Canada held by Messrs. Vickers. Further output at Woolwich was at once arranged for; 80 complete equipments had been ordered by the end of October, and at the end of 1914 the Ordnance Factories were instructed to proceed at the rate of six or eight a month. The first order to the Coventry Ordnance Works was given in August, and by the end of October the firm had promised 300 by the summer of 1915, and a further 150 as soon as possible, while a continuation order for 200 was given in December. The firm were from the first uncertain

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[1] P.M./G/7439. [2] D.D.G.(D.)141/1. [3] 94/G/6004; P.M./G/6473. [4] C.G.M./387/2.

[5] 94/G/640. In May and June there was delay due to dilution and other labour difficulties, and non-delivery of machines particularly for the new 60-pdr. shop at Elswick. Inspection and proof were rather slow, and certain inspection rulings had caused delay and some friction.

[6] D.M.R.S. 404.

whether they could keep to the rates of deliveries asked of them, and their deliveries were in fact seriously behindhand. In 1915 the Ministry of Munitions promised them all possible help, for instance, with advances of capital, supply of machinery and postponement of Admiralty work, in order to secure increased supplies in 1916; and undertook that they should have continuation orders if more 4·5-in. howitzers were required.

Production from new plant began in the spring of 1916, and during the summer the firm more than once asked for additional orders to keep their plant and sub-contractors employed. For a time part of their capacity was turned over to 6-in. howitzers, but towards the end of the year they were instructed to continue production of the 4·5-in. at their maximum capacity until further notice, and in August, 1917, they gave up 6-in. howitzer manufacture in order to concentrate on 4·5-in. In January, 1917, 24 equipments ordered by Canada shortly before the war were transferred to the British Government, and in April a similar transfer of 150 equipments was made.

Production of 4·5-in. howitzers was very much below anticipations in the early part of the war. The output from the Coventry Ordnance Works on War Office orders was very much in arrears, and production by the Bethlehem Steel Company was equally disappointing.

This howitzer was supplied to Russia in considerable numbers. At the end of 1915 it was decided that although Russia had asked for heavy howitzers, the 4·5-in. type should be supplied instead,[1] and 300 had been sent off by the end of May, 1916,[2] 100 more being shipped in September.[3]

(*d*) 6-IN. GUN.

One of the most remarkable features in the history of artillery is the demand for the 6-in. gun. Arising in 1916 and continuing till the end of the war, this demand was insatiable. Before the spring of 1916, little use was made of this type, and in September, 1915, the supply was considered adequate, but the growing importance of long range guns was reflected in enquiries made in April, 1916, when Messrs. Vickers were asked to state what guns they possessed of 6-in. or higher calibre,[4] and proposals were made for using guns from coast defence and the Navy or guns made for foreign governments. In June, Sir Douglas Haig's proposals opened a new chapter in the gun programme. Under Scale A 150 6-in. guns were required by the spring of 1917, and arrangements for providing them had to be put in hand at once. The Admiralty agreed to lend twelve guns,[5] and proposals were made for increasing the establishment by drawing on other available sources.

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[1] HIST. REC./R/1201.3/1.
[2] HIST. REC./R/1200/5.
[3] HIST. REC./R/1200/13. The Milner Report (1917) recommended that 50 should be sent to replace casualties, but owing to the Russian revolution, this was not done. In December, 1917, it was arranged that guns originally destined for Russia should be used by Great Britain or some of the Allies. (D.M.R.S. 404.)
[4] D.D.G.(D.)29; D.D.G.(D.)223.
[5] D.M.R.S. 404H.

All the armament firms were approached and considerable orders given. Between July and the end of the year 52 gun bodies had been ordered from Messrs. Beardmore and Messrs. Vickers, mechanisms being arranged for from Messrs. Beardmore, and the Ordnance Factories, and carriages from certain railway companies and from the Metropolitan Carriage Wagon and Finance Company. Messrs. Armstrong had also promised 28 equipments. These were all of Mark VII type, but by the end of 1916 this had to a great extent been superseded by Mark XIX. Of this type Messrs. Vickers were at first the sole makers, but by the end of 1916 the other three armament firms had all received contracts, the total ordered between August and December being about 300. The mechanisms were for the most part supplied by Messrs. Vickers.[1]

Owing to the urgent need of 4-in. guns for the Navy a great many of the 6-in. gun orders had to be reduced or cancelled. On 4 December, 1916, work on the 6-in. was suspended at Coventry and at Messrs. Beardmore's works, and partially at Messrs. Vickers' works, further reductions in Messrs. Beardmore's orders being made in January, 1917. During the next few months Admiralty work and repairs gave little opportunity for ordering new 6-in. guns, but from May, 1917, onwards the situation was easier.[2] In the summer, orders were given to the Coventry Ordnance Works and to Woolwich, while forgings were arranged for from Messrs. Firth and cradles from Messrs. Carmichael, James & Company. Greater use of new sources of supply was made during 1918. Forgings were made by Messrs. Steel, Peach & Tozer and Messrs. Hadfield, guns were made at Nottingham Ordnance Factory and proved and rectified at Leeds Ordnance Factory.

Despite production by the Ordnance Factory, the four armament makers and a number of lesser firms, and the use of guns drawn from various existing sources, deliveries of the 6-in. gun were never equal to the requirements of the Army. Production was seriously delayed by the repair programme and the need of guns for anti-submarine defence, and also by familiar difficulties, such as lack of forgings, in the late summer and early autumn of 1917.

A certain number of 6-in. Mark XIX guns were promised to America in 1918.

(e) 6-in. Howitzer.

Of this nature the 26-cwt. type, designed by Messrs. Vickers and first produced in 1915, was by far the most important. An experimental equipment was made in the autumn of 1914, and in the spring of 1915, 16 complete equipments were ordered from Messrs. Vickers. This firm were throughout regarded as the principal makers, and produced large numbers. Orders placed by the Ministry in 1915 amounted to about 500 equipments. A further 246 had been ordered by August, 1916, and by that time the firm's output was good. Between June, 1916, and April, 1918, 1,580 6-in. howitzer bodies were ordered from Messrs. Vickers alone. The demand for this type was so great,

[1] 94/G/4750.

[2] Hist. Rec./R/1200/57.

however, that other sources of supply had to be found. At the gun conferences, in July, 1915, it was decided to arrange for extensive production, and over 200 had been ordered from Messrs. Beardmore by the end of the year.[1] Messrs. Beardmore continued to make this type of howitzer until the end of the war, a contract for 8-in. howitzers being cancelled in 1918 in order to increase 6-in. production. Their deliveries were disappointing at first, owing to shortage of labour and machinery.[2]

In March, 1916, an order for 120 equipments was given to the Coventry Ordnance Works, and further orders were placed up to the summer of 1917, when it was decided that the firm should concentrate on 4·5-in. howitzer work. Deliveries from this source also were some months in arrears.

Orders for 100 equipments were given to the Ordnance Factories in January, 1916, and the Imperial Munitions Board of Canada received an order for carriages about the same time. In September, 1917, Messrs. Dick Kerr, Mather & Platt and the Rees Roturbo Manufacturing Company were given orders for howitzer bodies, the last named firm receiving a further order in February, 1918.

Russia was very anxious to obtain 6-in. howitzers, and at the end of 1915 enquiries were made as to the possibility of getting them from the Midvale Company. A contract was not placed immediately, but eventually 120 6-in. 26-cwt. howitzers were ordered from this source, and it was estimated that by the end of 1917, 86 of the 30-cwt. type would also be available for Russia from British casualties. By August, 1917, 88 of the 26-cwt. type had been delivered. Howitzers of this type were also supplied to Belgium, Italy and Greece.

(*f*) 8-IN. HOWITZER.

The demand for this nature was one of the first factors in upsetting the original plan that manufacture of each type should be restricted to two contractors.[3] Eventually it was made by Woolwich and all four armament firms, while lesser firms worked on components.

The first type of 8-in. howitzer was a conversion from the 6-in. naval gun. Experiments with this were carried out in the late autumn of 1914, and in December it was decided to convert 23 6-in. guns which were immediately available. The Ordnance Factories undertook 12, Messrs. Armstrong and Vickers four each, and Messrs. Beardmore three, all the mountings being supplied by Woolwich. The whole 23 equipments on the original orders had been delivered by May, 1915, and further guns were subsequently converted. In August, 1915, Messrs. Vickers' design of 8-in. howitzer (Mark VI), firing from its own carriage, was approved, and as the 8-in. was more mobile and quicker to make than the 9·2-in., it was decided to supply more of the 8-in. Messrs. Vickers, though the designer, were not one of its principal makers. The first substantial order was placed with them in March, 1916, for 50 howitzers. An additional 30 were ordered in the autumn, with 33 of Mark VII, an improved type adopted in 1916.

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[1] 94/G/645; HIST. REC./H/1200/16. [2] HIST. REC./H/1200/13.
[3] HIST. REC./H/1200/6.

In April, 1916, a small order for howitzer bodies was given to the Coventry Ordnance Works, who later undertook A tubes for this type. Messrs. Beardmore produced the howitzer in 1917–1918, their repair programme being adjusted to allow of increased output. The principal contractor, however, was Messrs. Armstrong. Their first contract for new howitzers was arranged in October, 1915; further large orders were given in May and September, 1916, while in November they were told to continue production at the maximum rate on the conclusion of existing contracts. Large numbers of mechanisms were also ordered from them.

Early in 1916 orders were also given to the Midvale Company, as has already been mentioned, and to Woolwich; and in 1917 new British firms were recruited. In, for instance, November Messrs. Beyer Peacock received an order for carriage cradles. Messrs. Hadfield received an order for 44 bodies in September, but the contract was superseded in April, 1918, by an order for 200 bodies.

This type of howitzer was particularly in demand in the spring and early summer of 1916. Supply prospects, however, were not very bright. Owing to the usual difficulties with machinery and labour, deliveries expected from Messrs. Beardmore from January, 1916 onwards did not begin until June, and were not completed till May, 1917, instead of August, 1916, while production at Woolwich had to be sacrificed in order to turn out naval guns.[1] In March, 1917, it was decided that, if necessary, production of 18-pdrs. and 60-pdrs. must supersede that of 8-in. howitzers.

In July, 1916, it was arranged that Russia should receive one in every three 8-in. or 9·2-in. howitzer equipments produced, up to the number of 150, after the British Army had received 426 equipments, and by 21 August, 1917, 38 8-in. howitzers had been supplied.[2]

At the end of 1917 the United States asked for 8-in. and 9·2-in. howitzers, and by the time of Armistice 125 8-in. had been handed over.

(*g*) 9·2-in. Howitzer.

In September, 1914, Messrs. Vickers were instructed to proceed with 16 9·2-in. howitzers, similar to the one made by them and approved just before the outbreak of war, a further 16 being ordered in October. In May, 1915, Messrs. Vickers asked for further orders to keep their capacity employed, and a third order for 16 complete equipments was given. In July, 1915, it was decided that Messrs. Vickers should be the recognised manufacturers of this nature.[3] The first order from the Ministry, for 120 equipments, dated from July, and was followed two months later by a continuation order.

[1] D.D.G.(D.) 146. [2] D.M.R.S. 404D.

[3] In July, 1915, Messrs. Beardmore received an order, but this was cancelled almost at once in favour of 8-in. howitzers. (D.D.G.(D.)221.) In 1918, the Cunard Steamship Co. made 69 carriages and 36 limbers. (94/G/1278.) On 29 August, 1917, the British Westinghouse Company received an order for 20 Mark I howitzer bodies (the Ministry to supply certain parts), but none had been delivered by July, 1918.

Early in 1916, when heavy howitzers were badly needed, the firm were asked to speed up production, and in May and October further large orders were arranged. By the end of the year deliveries were somewhat in arrears. Messrs. Vickers remained, however, the only British contractor, receiving large orders in 1917–1918.

At the end of 1915 the Bethlehem Steel Company received an order for 150 howitzers and mountings, promising delivery between June, 1916, and March, 1917. In July, 1918, however, deliveries were still not complete on this contract.

In 1918, 44 of these howitzers were handed over to the Americans. A few were also supplied to Belgium and Russia.

(*h*) 9·2-IN. GUN.

The 9·2-in. gun was ordered in small numbers only from Messrs. Beardmore, Armstrong and Vickers. Messrs. Beardmore made only Mark X equipments, receiving an order for four from the War Office in March, 1915, and another from the Ministry in September, 1916, for five guns. Messrs. Armstrong, who had designed the 35 calibre type, received orders for this gun (Mark XIII) in July and September, 1916, and June, 1917, and also supplied railway mountings for this and the Mark XV gun. The latter was supplied by Messrs. Vickers, who had in stock a number intended for a foreign power, and also received an order for three equipments in September, 1916. At the same time six Mark XIII bodies were ordered from them.

Delivery of these guns was delayed for more urgent work. Messrs. Vickers' contract of September, 1916, for instance, ought to have been completed by the end of June, 1917, but more than a year later no deliveries had been reported.

(*i*) 12-IN. HOWITZER.

Manufacture of this type was carried on by Messrs. Armstrong Whitworth, Messrs. Vickers and the Coventry Ordnance Works.

The howitzer was designed in the autumn of 1914, and was of two types, on rail and on road mountings. The first orders given at the beginning of October, 1914, were for 24 of rail type and 8 of road, the former being undertaken by Messrs. Armstrong, the latter by Messrs. Vickers. Some of the mountings for the rail type were made by the Coventry Ordnance Works.

Messrs. Armstrong contracted for a further 16 howitzers and railway mountings, in August, 1915, and in October, Coventry Ordnance Works undertook 10 howitzers of Mark I and railway mountings, the type of howitzer being subsequently changed to Mark III. Further orders for the new type were placed with them in 1916. Messrs. Vickers specialised in the road type of howitzer. During 1916 they received orders for 4 howitzers of Mark II, 18 of Mark III, and 9 of Mark IV, together with certain road mountings and additional mechanisms.

In November, 1916, all three firms were told that production of 12-in. howitzers at their maximum capacity was to continue until further notice, while during 1917 Messrs. Armstrong and the Coventry Ordnance Works took further orders for Marks I and V, and Messrs. Vickers for Marks II and IV and road mountings. Orders placed in 1918 did not produce output during the war.

(*j*) 12-in. Gun.

The 12-in. gun was a naval weapon, but could be modified for use in the land service. Two guns were delivered in the second quarter of 1918. In October, 1917, six railway mountings were ordered from Messrs. Vickers, but no deliveries on this contract had been made at the date of the Armistice.

(*k*) 14-in. Gun.

In November, 1916, Messrs. Armstrong received an order for 2 14-in. guns to be delivered by September, 1917, and 2 railway mountings. In September, 1917, the firm was asked to complete 10 guns ordered originally by the Chilian Government, and to provide railway mountings, by the spring of 1918. By November, 1918, 4 guns and 4 mountings had been delivered.

Messrs. Vickers were asked in January, 1918, to prepare 24 Russian guns for mounting. Three had been delivered by November, together with one mechanism.[1]

(*l*) 15-in. Howitzer.

In September, 1914, it was decided that 8 15-in. howitzers which had been ordered by the Admiralty from the Coventry Ordnance Works should be adopted for land service. The firm continued to be responsible to the Admiralty for the complete howitzers, but the Ministry ordered parts as required. Twelve of these howitzers were produced during the war.

VI. The Provision of Spare Parts.

A proper supply of spare parts was essential to the efficient working of an equipment, but requirements were very difficult to gauge owing to the multiplicity of items and the great difference in their importance. The original War Office plan, which was at first followed by the Ministry, was to order spares with each equipment, but this proved an unsatisfactory system. The armament firms could not supply spares in adequate numbers, without hampering their main work. General Du Cane urged in June, 1916, that better provision should be made, and in the autumn it was decided to order spares on the basis of monthly requirements, calculated by G.H.Q. on the basis of the number of rounds fired. The Ministry aimed at accumulating a six months' stock of spare parts, one month's stock being held in France, one month's on the way to France, three months' at Woolwich, and one month's passing through inspection.[2]

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[1] Eight inner A tubes were ordered from Messrs. Vickers in February, 1917, but the contract was cancelled after the Armistice.

[2] Conference between representatives of War Office, Ministry of Munitions, G.H.Q., 12 September, 1916.

At the beginning of 1917, the problem of spare parts, as of gun repair, became specially urgent since the guns in the field were wearing out faster than they could be replaced. Orders for spares were given to a large number of firms and part of the shell capacity turned over to gun work was utilised for the same purpose.[1] During April and May, 1917, the supply of spare parts fell below the quantities necessary for upkeep, and it was decided that a year's supply of spares, both for new work and repair should be obtained and kept at a Ministry store and not, as formerly, by the Deputy Director of Ordnance Stores.[2] A Gun Parts Committee was appointed to organise the supply of spares, and succeeded so well that in September, 1918, there seemed to be a danger of over-production.[3]

VII. The Repair of Guns and Carriages.

The erosion caused by firing a gun makes it inaccurate, decreases its muzzle velocity, and so lessens its range. If allowed to continue beyond a certain point, wear will make a gun incapable of repair, or even cause it to burst. The limits of wear differ in the various natures of guns, and during the war the theoretical margin of safety had sometimes to be invaded through lack of supplies.

Broadly speaking, the life of the gun is constant, and can be stated in terms of the rounds fired, though there are minor factors which tend to lengthen or shorten its life. The quality of manufacture has an important bearing, and the guns used early in the war were found to exceed their theoretical life. A good deal depends on the care the gun receives, and the skill and experience of the battery. Again, a very rapid rate of fire sets up great heat and tends to injure the gun. Very definite results follow from the strength of the charges used, and the life of a gun or howitzer can be lengthened very much by substituting a reduced charge for a full one.[4] During the war, a three-quarters charge was considered to cause only a quarter of the wear that followed the use of a full charge, and sixteen half charges were reckoned equal to one full charge from the point of view of wear and scoring.

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[1] (Printed) *Weekly Report*, No. 79, I. (10/2/17.) *See also* Vol. X, Part III, Chap. III. [2] D.D.G.(D.)144. [3] M.C. 773.

[4] The following table (D.D.G.(D.)140) shows the effect, as estimated in 1917, of using a proportion of reduced charges.

Nature.	Estimated life of Guns in rounds.	
	Full charge.	If half the rounds are fired with reduced charges.
18-pdr.	12,000	—
60-pdr.	4,000	—
4·5-in. How.	14,000	22,000
6-in. 26-cwt. How.	5,000	8,500
8-in. How.	4,500	7,500
9·2-in. How.	4,500	7,200
12-in. How.	1,500	2,200
6-in. Gun	1,900	3,000

The design of the driving bands of the shell also affected the life of the gun, and in this there was an opportunity for reducing wear. Greasing the bore of the gun was another method employed with some success, and attempts were made to enforce pauses during firing, to allow time for the guns to cool.

Methods of repair changed as the war went on. At first the usual process was to fit a short bore and chamber liner, but early in 1917 it was found that many of the new types were not suitable for this method or even for repair by a through liner. The short bore and chamber liner process was considered applicable only to the following natures :— 15-in. howitzer, Mark 1, 12-in. howitzer, Marks I to V inclusive, 8-in. howitzer, I to VI inclusive, 6-in. Mark XIX and 6-in. 30-cwt. howitzer. Through liners were to be used for 12-in. guns Mark I, 9·2-in. Mark III, and 6-in. Q.F.T.B.II. All other natures were to be repaired by fitting new inner or A tubes.[1] Eventually, repair by short bore and chamber liner was discontinued altogether, except at Woolwich, where the circumstances were exceptional.

Owing to the shortage of ammunition during the first nine months of the war, the guns at the front had very long lives, and it was not until there was a prospect of an ample supply of ammunition that the question of gun repair became important.[2] From the autumn of 1916 onwards the repair of guns presented a most serious problem.

The Battle of Verdun threw a great deal of light on the rate of wear of guns. In June, 1916, Woolwich was considered to have adequate capacity for all repair work,[3] and it was not until a month after the battle of the Somme began that important action was taken. The Army was firing an unprecedented quantity of ammunition and the guns were wearing out with unexpected rapidity. It was decided that the gun making firms must be brought in to supplement the work of Woolwich, and on 25 July, conferences were held at which Woolwich, the Design Department, and the armament firms were represented. It was decided to consider for the moment repair work for the remainder of 1916 only, and to hold a conference in the autumn to make plans for 1917.[4] A stock of A tubes and liners was to be secured as soon as possible. Woolwich and the armament firms stated that two guns could be repaired for every new one cancelled, and it was realised that some new production must be sacrificed for repair work. Arrangements were made for repairing by 31 December, 240 18-pdrs., without disturbing new manufacture, 100 4·5-in. howitzers at the expense of 50 new guns and 75 60-pdrs. at the expense of 37 or 38 new guns. The Admiralty supplied on request a list of firms which had done naval work and might be able to help with the repair of land service guns.

At a conference held on 28 August, 1916, it was estimated that practically no guns would last for a year, if ammunition were fired at

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[1] Repair of a 60-pdr. by new inner A tube took twice as long as repair by short bore and chamber liner, and three times as much material. (D.G.M.D./G/181.)

[2] On 21 September, 1915, the War Office drew attention to the necessity of making adequate arrangements for the repair of the large number of guns that had been ordered on the Ministry programme. (57/3/4905 in D.M.R.S. 200.)

[3] D.D.G.(D.) 140. [4] D.M.R.S. 404.

the offensive rate. It was suggested that badly-worn guns should be used up and sent home for repair at once, as if a large number of guns were fired evenly all would need repair at the same time. Later on, guns might have to be sent home when only partially worn so that they could be returned before the critical quarter of 1917. It was also suggested that guns should be condemned only for inaccuracy and not because in theory they had used up their lives.

The full repair programme put forward by the Ministry was approved by the War Office on 28 September, and steps were immediately taken to put it into effect. By this time, considerable numbers of guns were beginning to come back for repair. The allocation of types—apart from Woolwich—was, broadly speaking, as follows: Messrs. Armstrong, 12-in. and 9·2-in. howitzer, 60-pdr. and 18-pdr. gun; Messrs. Vickers, 12-in. and 9·2-in. howitzers, 6-in., 26-cwt. howitzer and 18-pdr. gun; Messrs. Beardmore, 6-in. 30-cwt. howitzer and 18-pdr. gun; Coventry Ordnance Works, 8-in. howitzer, 6-in. gun and 4·5 in. howitzer.

Arrangements were made for carriages to be sent direct from the port to the works where they were to be repaired.[1] Thus 12-in. howitzer and 9·2-in. siege carriages went to Messrs. Vickers (Barrow), while the 12-in. railway type and the 8-in. Mark VI carriages went to Elswick. Woolwich received 8-in. Marks I to V, and 60-pdr. Mark I, 6-in. 26-cwt. went to Erith, 4·5-in. to Coventry, and 60-pdr. Mark II and 18-pdr. to Elswick.

The position was very serious. In October the number of worn guns in the field was increasing every week and if repaired guns were not forthcoming soon, guns from new equipments would have to be used, thus reducing the number of units in the field. Woolwich and the armament firms were told in November to push on repairs with the utmost speed, if necessary sacrificing new production for the time being. Repaired guns might be issued, if need arose, without carriages or mechanisms. The Ministry would try to help in overcoming labour difficulties, and proposals for extensions of repair plant must be submitted at once. Extensions of gun forgings plant were contemplated at Messrs. Vickers (Sheffield), Messrs. Firth's (Sheffield) and other works, and were sanctioned at Woolwich, while Messrs. Beardmore and Woolwich were authorised to acquire more heat-treating plant.

In order to hasten the work of repair, a branch of the Inspection Department was established at Southampton towards the end of 1916. Here carriages were received from the front, sentenced, stripped of parts damaged beyond repair and despatched to the repairing firms. Later, in order to relieve Woolwich, the inspection and sentencing of guns was carried out to some extent at the Southampton shop and at repair factories.[2]

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[1] A plan for sentencing guns and carriages at the port of embarkation and sending them direct to the repair factory did not prove feasible. (HIST. REC. H/1200/6.)

[2] At first Southampton could deal with no guns heavier than the 5-in. howitzer. In December, 1916, there was such congestion at Havre and Southampton that certain natures of guns and carriages were sent straight to Woolwich instead of passing through Southampton.

Great developments took place early in 1917. At a conference on 13 February it was decided to widen the field of operations for the manufacture and repair of guns and the supply of spare parts.[1] Approval was given to a plan for executing certain minor repairs at Southampton, and ultimately all breech mechanisms were repaired there. In February, Sir Glynn West took over the direction of repair, and spare shell capacity was turned over to this work. Mr. Anderson was appointed Director of Additional Gun Repair, with the duty of providing forgings for repair work. Large new extensions were put in hand by the gun makers, and extra firms, such as Messrs. Cammel Laird, were recruited for work on forgings. Messrs. Cammel Laird, in addition, made extensions in March, 1917, for repair work, and other new firms also received orders.[2] As has already been seen, certain National Projectile Factories took up this work, and ultimately the repair of 18-pdrs. centred round the Leeds National Ordnance Factories. It was estimated that by the end of September, 1917, the new shops would be capable of relining the following guns monthly: 500 18-pdrs., 120 4·5-in. howitzers, 91 60-pdrs., 12 6-in. howitzers, 39 8-in. howitzers, and 32 9·2-in. howitzers.

The early part of 1917 was an anxious time. Owing to the delay in the opening of the offensive worn guns were not returning from the front in anything like the expected numbers. This meant that whenever the offensive began the guns would have still less of their lives remaining, while the estimated number of repaired guns would not be available. Repair work had also to be withdrawn from Messrs. Armstrong, the Coventry Ordnance Works, and Messrs. Beardmore in favour of new production, but it was hoped that the establishment might be kept up by using badly worn pieces on the defensive front and concentrating all the comparatively new guns on offensive work. "The ultimate gun reserves of the Army should be a repairing organisation in the highest state of activity and on the greatest scale."[3]

The repair of carriages was difficult to arrange as the extent and nature of damage varied in different cases. In March, 1917, it was decided to strip off all serviceable parts and build them up into as many complete carriages as possible without trying to keep the identity of any particular carriage. Damaged parts when repaired were to be treated in the same way, and non-repairable parts were to be sold as scrap. In May, 1917, it was decided, in order to improve the rate of repair, to hold a stock of spare parts sufficient for a year's work.

In the autumn of 1917 supplies of repaired guns were again disappointing, largely because of the inevitable delays in deliveries from new firms. For instance, deliveries of 4·5-in. howitzers from the Austin Motor Company and of 60-pdrs. from Messrs. Harper Sons & Bean and Messrs. Hadfield were all behindhand. Moreover, worn guns

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[1] (Printed) *Weekly Report*, Nos. 79 and 80, I. (10/2/17 and 17/2/17.)

[2] In June, 1917, an open contract for 6-in. 26-cwt. howitzer repairs was given to Dick, Kerr & Co. Deliveries by 21 November, 1918, amounted to 121. There had been no rejections.

[3] Minute by Mr. Churchill, 15 August, 1917.

were again not available in adequate numbers. The Ministry complained that only 20 per cent. of the 6-in. howitzers, 40 per cent. of the 8-in. and 9·2-in. howitzers and 50 per cent. of the 18-pdrs. promised had been sent back from France. It took three months to repair a gun or howitzer, and the Army commands had to weigh the respective claims of immediate and future needs. The return of partially worn guns to be repaired in time for the 1918 spring offensive was proposed, but Sir Douglas Haig, on 11 November, said that it was quite impossible to withdraw the required number of guns. The position at the beginning of 1918 was very unsatisfactory, as appears from the following table :—

STATE OF WEAR OF GUNS IN THE FIELD.

	Position on 17 June, 1917.		Position on 27 Jan., 1918.	
	Numbers of Guns available.	Numbers of Equivalent Full Lives.	Numbers of Guns available.	Numbers of Equivalent Full Lives.
18-pdr. ..	2,606	1,613	2,887	1,162
4·5-in. How. ..	816	408	844	256
60-pdr. ..	350	232	361	240
6-in. How. ..	424	288	808	563
6-in. Gun ..	50	31	85	56
8-in. How. ..	112	73	202	158
9·2-in. How. ..	176	111	190	126
12-in. How. ..	30	21	42	22

The Minister drew attention to the fact that the position compared very unfavourably with the position in June, 1917, when there had been much heavy fighting.

In February it was arranged that all guns nearing the end of their lives—except the 4·5-in. howitzers, which could not be spared—should be sent home, and by 15 March, all the 18-pdrs. with a life of less than 2,000 rounds left had been turned out of the line.

The possibility of transferring repair work to France was examined during the autumn of 1917. It was decided that for the time being oversea repair of guns was not feasible, but plans were made for repairing carriages, which were more bulky than guns to move, required less elaborate repair shops, and for which skilled labour could be provided in France. The question was discussed with G.H.Q., who estimated that their requirements for carriages could be considerably reduced if all repairs were done in France.[1] The equipment of a large factory at Creil was begun, but the German advance in the spring of 1918 made it necessary to abandon the project.[2]

[1] D.M.R.S. 535.

[2] Vol. II, Part VII, p. 8.

CHAPTER VI.

REVIEW OF SUPPLY DIFFICULTIES.

I. Introduction.

There were many difficulties in the building up and working of a supply system on lines that would give the minimum of friction, and of waste of time, effort and money. One great problem was to employ labour and machinery, in the quality and quantity available, without a break, yet in such a way as to meet the real needs of the Army. For instance, it was feared at a certain time that too many forgings, or too many spare parts, would be produced. Sometimes it was impossible to cancel a contract without a heavy loss of money, and inferior supplies had to be accepted long after a better design had been adopted. Another problem was to balance the output of guns and ammunition and of guns and carriages.

The unreliability of estimates with regard to requirements, resources and probable deliveries made the task of organisation supremely difficult. Limitation of profits lessened the manufacturers' incentive to swift and good production and the process of classifying certain trades as "War" or "Munition" work led to some anomalies. For instance, at the end of 1915, it was ruled that building munition shops was not munition work, and the contractor had therefore no legal power to retain his employees. Numerous difficulties arose owing to the conflicting interests of finance, inspection and supply. The Priority Department refused to help with the supply of materials for which the formal contract had not been placed. Later in the war there was the difficulty that equipments from America arrived very irregularly, and in many cases alterations were required on arrival. The supervision of American orders gave an immense amount of trouble. Officials were appointed from time to time to supervise the progress of manufacture in America, but their authority did not always carry the same weight as with British firms. The American manufacturer compared unfavourably with the British as to the price, rate and quality of production. Moreover, transport to Europe involved delay, danger and expense. Besides these disadvantages there was the need of limiting foreign orders as far as possible owing to the adverse rate of exchange.

II. Inspection and its Difficulties.

With the growing volume of gun manufacture all over the country, inspection had to be organised on a greatly extended scale.[1] Local inspectors were allotted to different areas, with the duty of supervising

[1] The following figures illustrate the development of inspection outside Woolwich:

	February, 1915.	February, 1916.
Inspectors	—	3
Assistant Inspectors	16	132
Examiners, &c.	349	5,482

manufacture by the firms in each district. Thus mistakes were discovered and rectified with the minimum of delay, and suggestions for improving output by changes in organisation or design brought quickly to the notice of the central authorities. The disadvantage of this arrangement was the difficulty of maintaining a common standard. Personnel was scarce, as civilians could get better pay by working for contractors, and dilution and recruitment drained a staff in which knowledge and skill were essential. Thus there were complaints, particularly against out-station inspectors, among whom there were great differences in ability, experience and standards. It was difficult also for the inspectors to keep in perfect liaison with the authorities in France. Thus in April, 1918, the base workshops were exacting a higher standard than was required by the inspectors at home, who had relaxed their demands in order to meet the emergency of the moment. About this time, the Inspection Department sent representatives to the Calais and Havre Depôts, to improve liaison with the authorities at the front. Officers of the Inspection Department also visited France from time to time to examine special difficulties.

Occasionally the temporary relaxation of standards or the use of substitute materials were necessary in order to obtain supplies. Thus, in October, 1914, the manufacture of 60-pdr. breech rings in nickel steel instead of carbon steel was sanctioned, while later on (June, 1917), when supplies of nickel had become short, nickel steel was superseded by carbon steel in certain heavy howitzers.[1] Other modifications permitted so as to hasten output included the use of steel castings in certain parts of 60-pdr. carriages, a modification to simplify repair of cradles,[2] and the manufacture of 16 6-in. guns without top traverse.[3] Material and products differing slightly from specification were sometimes accepted if they would pass proof.[4]

The routine of inspection was sometimes curtailed in order to hasten supply to meet an urgent need, *e.g.*, in the spring of 1916, in the case of heavy guns made by reliable makers, and in March, 1918, when certain 18-pdr. carriages were issued without firing proof.[5]

The traditions of peace time were with difficulty adapted to the exigencies of the war. There were numerous complaints that the Inspection Department maintained an unnecessarily high standard. They were accused, for instance, of rejecting 60-pdr. chambers for "a negligible error," recurrence of which would in any case be prevented by the use of new gauges. Again, in July, 1916, Messrs. Vickers complained that an examiner had been told to reject a recuperator for "an infinitesimal defect." The vigilance of the Inspection Department was, however, justified by the serious consequences of the failure of a gun—not only heavy casualties to British troops, but the destruction of their *morale*.

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[1] D.D.G.(D.) 286. [2] D.D.G.(D.) 182. [3] D.D.G.(D.) 230.

[4] D.D.G.(D.) 204. Contractors agreed to replace doubtful or inaccurate parts if they failed from other than extrinsic causes within six months after delivery. A contractor was responsible for a gun passing the test even when made from a forging which, though differing from specification, had been accepted by an official inspector.

[5] D.D.G.(D.) 183.

Delay frequently resulted from proof and after-proof inspection, and this difficulty came to the fore in the autumn of 1917, in connection with 6-in. howitzer equipments. Delay was also caused by the re-stripping and inspection of carriages on arrival in France. This was considered necessary as late as the autumn of 1918, to guard against defects which had been discovered in the past, and because the carriages had been in stock for three or four months, and might have been damaged in transit.[1] As experience was gained a good deal of delay and inconvenience was removed by better organisation. For instance, in 1916 it was arranged for 18-pdrs. to be proved at Barrow, where they were made, instead of being sent to Sheffield,[2] and a considerable saving was made in the after-proof transit of the 9·2-in. howitzer.[3]

The work of inspection became heavier as the war continued. At first Messrs. Vickers and other firms had been allowed very largely to test and inspect their own work, especially work of their own design. This arrangement proved unsatisfactory, however, owing to variations from design and loss of interchangeability, and on 29 October, 1916, the firms were told that in future inspection " as for sealed pattern equipments " would be applied to various other natures.[4] It was pointed out also that sub-contractors must be made to understand the necessity of conforming to the Government inspectors' decisions. Inspection of firms new to gun work had necessarily to be particularly stringent, on account of their inexperience. Moreover, contrary to the usual practice of the great armament makers, minor firms were not always careful to notify defects, and sometimes tried to conceal them.

The quality of the contractors' work was, for the most part, good, though defects in workmanship were inevitable when manufacture was carried on by many different firms at a very high speed and with great difficulties as to material and labour. One of the commonest complaints was that foreign matter—filings or grit—had been found in the recuperator cylinders of gun-carriages. For instance, in the autumn of 1916, certain 12-in. howitzers were found to be defective in this way,[5] as were 6-in. and 8-in. howitzer carriages from another firm. A year later it was reported that the 18-pdr. recuperators made by one firm were free from foreign matter, which occurred in 30 per cent. of those made by another firm. Carelessness and poor supervision offered a possible explanation. An improved method of proof was expected to alleviate the difficulty, but only did so to a certain extent. At the end of 1917, however, G.H.Q. reported an improvement in the " finish " of recuperators.

Complaints were also made of equipments delivered in a rusty condition owing to their not having been painted, or not properly greased, or exposed to the weather at some stage. There were so many stages in the handling of an equipment between its departure from the maker's works and its issue to a unit in France that it was often difficult to fix the responsibility for the trouble. The provision of protection against the weather had improved by April, 1918.

[1] Besides inspection of carriages at the Base Depôt, it was usual for equipments to be re-inspected at the Army Corps Artillery Park.

[2] D.D.G.(D.) 144/1.

[3] HIST. REC./R/1200/24.

[4] D.D.G.(D.) 144.

[5] D.M.R.S. 404 P. I.

Other mistakes and defects were the manufacture of leather packings with the flesh side as the working face;[1] improper packing (1918);[2] buffer cylinders made too large in the box, so that the sub-contractor could not finish machining them,[3] and unsatisfactory carriage repair work.[4] In April, 1916, sand flaws were found in the jackets of howitzers from a certain firm.[5] The work of sub-contractors was occasionally thoroughly unsatisfactory; for instance, wheels made by one motor company were poor in material and workmanship.

In December, 1917, it was reported that certain carriages and mountings did not fit, although they were intended for use together. The maintenance of interchangeability was considered by the Army a point of the utmost importance, as without it an equipment might be put out of action for lack of a comparatively unimportant part. From the point of view of supply, the problem demanded careful design, vigilant inspection and a high standard of manufacture, and as the circle of gun makers was widened to include new firms of varying capacity, it became extremely difficult to prevent or trace divergencies.

One common cause of complaint was the delay in incorporating improvements in manufacture. For instance, in September, 1917, it was stated that certain modifications had to be carried out in France as they had not been made in England. In 1918 one armament firm were still making forgings for repair by the short bore and chamber liner method although it had been superseded.[6] In some cases, the delay in making modifications or the loss of interchangeability was due to misunderstanding, or lack of drawings or defective manufacture. Very often, however, it was sanctioned by the Ministry to avoid greater evils. Minor changes in design were made throughout the course of manufacture of almost every type, and if introduced at once into supply, generally involved either delay or financial loss. For instance, in November 1915, the Coventry Ordnance Works were told to suspend many of the 12-in. howitzers as the design had to be improved, but the new pattern was not settled until the end of January, 1916.

III. Shortage of Materials and Machinery.

As the war continued the difficulty of obtaining materials and machinery for gun work became more and more serious. In both cases the Ministry had to help in provision and allocation, so as to make the best use of the resources available.

The lack of steel and forgings was due partly to the enormous demand and the consequent strain on home supplies, partly to the shortage of shipping and losses at sea, and in some degree to labour trouble.[7] Output of guns suffered accordingly. For instance, in October, 1917, owing to lack of material, Messrs. Armstrong had to

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[1] D.M.R.S. 404 P. I. [2] D.M.R.S. 404 P. II. [3] D.D.G.(D.) 144/1.
[4] D.M.R.S. 404 P. II. [5] D.D.G.(D.) 143/1. [6] *See* above, p. 76.
[7] For instance, the strike at Messrs. Beardmores' in the winter of 1917–18 (HIST. REC./R/1200/34). Delay in railway transit was another factor.

reduce their estimate of deliveries of 60-pdrs. from 68 to 40 monthly.[1] Another case of shortage occurred in January, 1917, when 600 tons of steel plate were supplied against a requirement of 750 tons, and material for carriages was cut down by 12 per cent.[2]

The armament manufacturers made many applications for help in obtaining material, and the Ministry had to allocate supplies to the most urgent classes of work. For instance in August, 1916, it was asked to procure forgings for the Coventry Ordnance Works, and at the end of the year Messrs. Vickers asked for help in obtaining rough forgings which had passed test.[3] In May, 1917, it was arranged that Messrs. Armstrong should hold a stock of steel for gun carriage repairs and despatch it to manufacturers as requested by the Ministry from time to time.

The Ministry had also to stimulate production of forgings. The armament makers were obtaining all their forgings from the Ministry, and therefore could not supply other firms. Early in 1917, an improved supply of forgings for repairs was organised, and later for new work, considerable extensions of forging plants being arranged for. Messrs. Cammell Laird, Hadfield, Steel Peech & Tozer and John Brown were among the firms receiving orders for gun forgings during 1917.

The shortage of machinery, which was particularly acute during the early part of the war, was due to various causes, including the high degree of skill required for making jigs and gauges, and delay in deliveries from America. The Machine Tool Department of the Ministry was formed to deal with supplies of machinery,[4] a large number of machine tools for gun making being ordered by Woolwich and the armament firms on the Minister's account. Pressure was often put on the tool-makers to hasten supplies, and steps were taken to distribute existing tools to the best advantage; for instance, in 1916 surplus machines, which belonged to the Government, from Coventry Ordnance Works, were rented to Messrs. Armstrong Whitworth.[5] Early in 1918 a plan was made for supplying all the 18-pdr. machinery that was available to certain firms, which could thus concentrate on the manufacture of mechanisms, and meanwhile the output of machinery was hastened so that more firms might join in the production of mechanisms.[6]

IV. Labour Difficulties.

Labour problems formed some of the most serious difficulties connected with the supply of guns. The armament firms appealed constantly to the Ministry for help in keeping what labour they had and

[1] D.D.G.(D.) 141/2.

[2] The quality of steel was sometimes poor, Messrs. Vickers had trouble of this kind early in 1917.

[3] D.D.G.D.(D.) 144. At another time, Messrs. Vickers were pressed to hasten supply of gun forgings to the Midland Railway Company.

[4] *See* Vol. VIII, Part III, Chap. II.

[5] D.D.G.(D.) 139/1.

[6] In January, 1916, it was thought that machinery ordered for Russia might be used for some months, being very badly needed in England. (Hist. Rec. R/1200/17.)

in obtaining more.[1] The Ministry had to prevent the recruitment of men whose services were vital, to distribute labour, especially skilled labour, to the best advantage, and to enforce the principle of dilution and the employment of women to the utmost limit of safety. The policy of the Ministry was as far as possible to ascertain contractors' labour requirements in advance, so as to have the greatest possible opportunities for meeting them.

Early in the war much difficulty was caused by competition between firms for the available labour, and by employees leaving at very short notice. For instance, at the Coventry Ordnance Works' shops in Scotstoun the output of 8-in. howitzer carriages was jeopardised by the departure of from 80 to 100 war munitions volunteers at the end of their six months' engagement (1915). Again, Messrs. Beardmore lost a large number of workers because the Government would not pay allowances to the dependents of men brought over by shipping companies from Canada. There were many cases—for instance, at Messrs. Beardmore's in 1915—in which the men left to go to other firms or districts where higher wages could be obtained.[2] The Munitions of War Act (1915, amended 1916 and 1917) checked these proceedings, but the employees were often able to obtain their release by pleading a plausible excuse before a local munitions tribunal. A favourite and often successful excuse was that the employer did not give Sunday work, which was popular because the employee could earn double pay on Sundays and then take two days' holiday in the week. Messrs. Armstrong gave up Sunday work after a few months' trial in 1916, as they found it unprofitable.

Many other labour difficulties arose later on. For instance, the recruitment of colliers hampered the supply of coal to gun-making firms, and output fell off accordingly.[3] In March, 1916, Messrs. Armstrong attributed the delay in 60-pdr. production partly to lack of labour and dilution difficulties, and again in May complained that labour shortage was particularly acute at York and Elswick. At York skilled men were needed to train women, and the experiment of employing soldiers had not been satisfactory. Skilled labour was scarce at this time, and by September, 1916, the position was very serious.

The labour requirements for gun manufacture were then estimated at 857 skilled and about 430 unskilled men, besides 70 skilled and 35 unskilled for the extra long range guns. For gun repair, about 900 skilled and 490 unskilled men were required, besides an indefinite number required for carriage repair and for making spares and accessories in connection with repair work. With the urgent naval demands of the autumn the lack of skilled labour was felt keenly.

Recruiting difficulties were prominent during 1917 and 1918. In the spring of 1917 it became known that all semi-skilled and unskilled men between the ages of 18 and 22 were to be taken from the engineering trades and from many other occupations which had a direct bearing on munition work. The Military Service Act of 1918 made the position

[1] D.D.G.(D.) 141/1 : HIST. REC./R/1200/24.
[2] D.D.G.(D.) 120.
[3] January, 1916. (HIST. REC./R/1200/17.)

still worse. The Ministry considered very carefully what measure of protection for certain kinds of workers was desirable and feasible, but it was found impracticable to exclude certain classes altogether, and the Minister said that no man who could be replaced must be held back from the Army.

The skill and strength required for work on guns made dilution very difficult, and impossible for the heavier natures, while unskilled workmen and women under training were slow, and caused wastage through mistakes.[1] Inferior labour was also very difficult to turn over to new work.[2] Moreover dilution sometimes caused labour troubles, and the armament firms were reluctant to adopt it. At a conference in January, 1916, the Minister urged that women should be employed as far as possible, and said that opposition must be faced and overcome. It was pointed out that at the works of two sub-contractors, Messrs. Lang and Messrs. Weir, women had been introduced without any labour trouble arising. Similarly, in the comprehensive general orders given to the armament firms in November, 1916, the Ministry instructed the firms to take immediate steps towards dilution, and for training female labour. Unskilled men, though essential to the gun-making firms, were usually of the exact physique required for the Army, and it was difficult to prevent their recruitment, or to justify it to the military authorities and the public. The shortage of personnel was also felt among higher grade workers, such as draughtsmen, and in the staffs required for organisation and management, the combination of technical artillery knowledge and engineering skill being rare.

Various restrictions on output, imposed in some cases by the Amalgamated Society of Engineers, hindered production. For instance, early in 1917, Messrs. Vickers reported that when their women were off duty the male supervisors would not work more than one machine at a time, although they could easily have done so. In January, 1916, at Messrs. Craven's (Manchester), the Amalgamated Society of Engineers broke their pledge not to hinder dilution with female labour. The use of Irish unskilled labour and military working parties also led to difficulties with the English labour leaders.

At the best of times the labour problem needed very careful handling. It was useless to emphasize the vital need of production if the workmen saw large numbers of guns or carriages waiting for weeks for proof or despatch, or if rejections were made for apparently trifling defects. Another complaint was that the inspection of factories with a view to recruiting was carried out by a young man who seemed himself to be perfectly fit for military service.

Considerable loss of output was due to strikes. As early as April, 1915, there were demarcation disputes. Strikes occurred at Coventry in 1916. In May, 1917, there was serious trouble; all the armament firms were affected as well as Woolwich, and many works in the London

[1] At a conference on 5 July, 1915, it was stated that "no dilution was possible for gun manufacture."

[2] The value of skilled men was often much greater than their numbers would suggest. For instance, in January, 1918, the removal of eighteen men from Messrs. Armstrong's proof range at Ridsdale meant that half their output would be lost during January and February.

district. By 15 May, Messrs Vickers' monthly output from Sheffield and Manchester had already fallen by 33 per cent., Erith also was affected, and though Barrow was then normal it would eventually be upset by the stoppage at Sheffield.[1] At Coventry the men had returned to work by 15 May, but meanwhile output of guns, carriages and mechanisms had been lost. Only half Messrs. Armstrong's employees at Openshaw had returned, though attempts to spread the strike to Elswick had failed. At Woolwich nine-tenths of the operatives were "out," and gun and carriage work was stopped. In the London area many firms making spares and accessories were still idle on 18 May. It was estimated that the effects of the strike would be felt for twice the time of its duration, and indeed they lasted until July.[2]

The next serious strike occurred immediately after Christmas 1917; Messrs. Beardmores' employees in the carriage shop were out for seven days, and many of the others for six weeks. Steel and forgings were lost as well as guns and carriages.[3] At Sheffield it was estimated that the strike had involved the loss of two 6-in. Mark VII guns, four 6-in. Mark XIX guns, 20 18-pdrs., 10 6-in. 26-cwt. howitzers, two 3·7-in. howitzers, three 8-in. Mark VII guns, and four 9·2-in. Mark II, besides certain repairs and carriages.

V. The Finance of Gun Manufacture.

The finance of gun manufacture presented many difficulties. In common with all munitions, supply was necessarily the first consideration; the absence of competition made all values abnormal, and in the case of guns, even after four years of war, no standard prices had emerged.

At the outset the cost of production was an unknown quantity, and varied markedly in the estimates of different firms; the difficult, elaborate and lengthy process of manufacture making standardisation impossible even in the details of production, and infinitely more so in cost. Again, the cost of material and labour was constantly changing, and during the time necessary for building a gun might transform completely the financial and economic conditions of the process. Further, the armament firms had to make enormous extensions to their buildings and plant, and it was a very complicated problem to arrange the form in which they should be repaid for the outlay. The demands of the war could only be temporary, and pre-war standards of profit were irrelevant when the armament makers were taking immense risks in order to meet current needs.

For the first year of the war the finance of gun production, like everything else, was improvised. It was impossible to defer placing orders until prices had settled. If costs had been calculated hastily, the estimate would have been so inaccurate as to lose all value, and to delay until they could be worked out carefully would have been disastrous. Throughout the war, in fact, a definite order often

[1] There was no serious trouble at Messrs. Beardmore's Glasgow Works.
[2] D.M.R.S. 404D. [3] HIST. REC./R/1200/34.

preceded the formal contract, and the price was settled much later.[1] There was always so much difficulty in estimating costs that the best plan seemed to be for contractors to submit tenders which were compared with the prices charged by other firms and with estimates from Woolwich and the Admiralty. If a suggested price seemed excessive, the contractor was asked to reduce it. For instance, in September, 1918, Messrs. Armstrong and Messrs. Vickers were requested to revise their prices for 60-pdr. carriages, as Messrs. Armstrong's quotation was more than three times the Ordnance Factory's price. Woolwich estimates, however, were not directly comparable with those submitted by the armament firms, since they contained nothing analogous to profit, the establishment charges did not cover exactly the same classes of expenditure and the value of land, buildings, power and water had not the place that it occupied in the calculations of the armament firms.

In some cases contractors reduced prices which were considered too high, but if they insisted on the original figure it was often accepted without further controversy. For instance, in 1916, Messrs. Armstrong submitted a price for painting 60-pdr. equipments which was considered excessive, but was nevertheless ultimately accepted.[2]

In many cases an increase in the cost of labour while the contract was in progress was expressly excluded from the conditions governing an agreement, since the risk was so great that contractors, and particularly sub-contractors, would otherwise have quoted much higher prices in order to make themselves safe.[3] When manufacture of a new type was begun, a contractor was sometimes allowed to fix his price on the basis of cost and a certain profit. " Cost " included the actual price of materials and labour, together with an agreed rate of establishment charges. Attempts were made to limit this class of contract, which offered no incentive to economy, to cases of extreme urgency; it was suggested in the spring of 1918, for instance, as the best method of getting quick supplies of 18-pdr. mechanisms.

The financial help given by the Government to the armament firms in the shape of capital advances was a very important factor in the development of gun supply. At first the firms paid for their own extensions or borrowed money for them from the Government, the extensions thus becoming the property of the firm in either case. When working out the prices of equipments, the manufacturers were allowed to include capital charges, and if they had received a Government loan it was usually repaid by a rebate in prices. For instance, in August, 1915, the Coventry Ordnance Works arranged a rebate of this kind.[4]

[1] In December, 1916, Mr. Ellis pointed out that there were still many contracts for gun equipments outstanding for which no prices had been arranged. (D.D.G.(D.) 221.)

[2] Contracts/C/1591.

[3] The offer of a bonus for deliveries before the specified time was sometimes made, and this method was adopted in 1915 to encourage Coventry in speedy production.

[4] D.D.G.(D.) 141/2.

At first production was so vital that the cost of extensions was hardly considered at all. For instance, in July 1915, the proposed extensions at Messrs. Armstrong's, Messrs. Vickers and Coventry were sanctioned not on the basis of cost but of increased output. By September, 1915, however, it had been arranged that extensions should be paid for by, and remain the property of, the Government,[1] the firms concerned having the option of purchase at the end of the war, and meanwhile being charged for depreciation of the Government property that they used. This charge was to be met by a reduction in the price of the supplies thus produced.

Later on all extensions had to be sanctioned by the Ministry, and a closer scrutiny of their financial aspects was possible than at the beginning of the war. The high prices that prevailed early in the war were believed to be due largely to the use of sub-contractors who had to be educated and inspected by the main firms, the expenses thus incurred being sometimes reflected in the price of the finished product. In 1916, therefore, the Ministry decided to place contracts for wagons and limbers direct with the makers (railway companies and similar firms) thus eliminating the middleman's charges. In October, 1916, when placing large orders with the armament firms the Ministry gave instructions for the insertion of a break clause providing that sub-contractors' prices were not excessive. At the same time the firms were instructed to order material in such a way as to avoid loss to the Ministry if the contract was cancelled. It was suggested that the best method, to be adopted after the first six months, would be to order material on the basis of monthly requirements.

The new policy of ordering spare parts on the basis of monthly requirements[2] tended in the direction of financial economy as well as adequacy of supply, since the increased size of the orders reduced the cost of production.

The policy of placing continuation orders before existing contracts had been completed was also justified from the points of view both of supply and finance. In October, 1916, Woolwich and the four armament firms received large continuation orders and were told to continue production of certain natures at their maximum capacity until further notice. Messrs. Armstrong Whitworth suggested that in order to avoid confusion a distinction should be drawn between their continuation orders and those already given, and that they should notify the Ministry when fresh orders were needed to ensure continuous production.[3] Doubtless for financial purposes this was the most satisfactory plan, and in February the firms were instructed to inform the Ministry when further orders were required.

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[1] It was realized that much of the plant would be useless to the armament firms after the war. (D.D.G.(D.) 139.) [2] *See* p. 74.

[3] D.G.O.S./G/23. Letter of 7 December, 1916, "At the present time we have various orders for guns or equipments which in the aggregate amount to a considerable number. As we fear confusion will result between these orders and the continuation orders which the Ministry desire us to proceed with, we suggest that the whole of these should be consolidated. In this case we will undertake to notify the Ministry when the work in hand has reached such a stage as to warrant further orders being given to us in order to ensure continuous deliveries at our maximum output."

Owing to the supreme value of time the supply department often placed orders without waiting for financial sanction. In July, 1916, the Contracts Department defined its position in cases where orders were so given, and it was approached later for ratification.[1] As regards guns and gun equipments (wagons and limbers being excepted), the Contracts Department recognised that this must be the usual course, for the supply department alone was familiar with the existing capacity, while cost was very difficult to estimate and price could not be controlled. Thus the Contracts Department definitely disclaimed responsibility for these transactions.

When the repair question became urgent, extensions were arranged on the basis of verbal sanction by Sir Glynn West and others, and the schemes were not submitted for approval to the Munitions Works Board until they had already begun to materialise. As late as the autumn of 1917 the supply department was authorising capital expenditure without consulting the Finance or Contracts Departments.

The finance of repair work, apart from extensions, was in many ways more difficult to arrange than that of new production. The extent and value of necessary repairs varied indefinitely in different cases. Repair of guns could be standardised to some extent, according to the method of repair adopted, but with regard to carriages the problem was highly complex, since the time and labour required for stripping, the value of the scrap, and particularly the approximate rate of establishment charges were difficult to appraise.

At the Coventry Ordnance Works' suggestion, it was arranged that each firm should hold a stock of parts most likely to be needed for repair work. These parts (which were to include serviceable parts taken from non-repairable carriages) were to be the property of the Ministry, and might be placed in the custody of a Ministry official. This simplified finance by eliminating from the cost of repair the most important part of the material used.

In general, the Ministry proposed that payment for repair work should be on the basis of cost of materials, labour, a percentage on productive labour for establishment charges and profit; the firms' books were to be open to inspection. The different firms suggested different rates. Messrs. Armstrong proposed 125 per cent. overhead charges and 10 per cent. extra for foremen, and justified these rates on account of the expense of repair work, the large space required, the high proportion of unproductive labour, and the constant attention needed from foremen. Eventually, however, the extra 10 per cent. was given up and the overhead charge fixed at 115 per cent. The Coventry Ordnance Works suggested 90 per cent. as overhead charges, since it was probable that Ministry machines would be used for about half the work, and the size of the orders lessened the proportionate cost of establishment charges. This arrangement was sanctioned.[2]

[1] D.D.G.(D.) 223. [2] D.D.G.(D.) 140.

The terms of Messrs. Vickers' "repair" contract were arranged as follows :—[1]

1. Cost of direct labour.
2. Oncost at 90 per cent. on direct labour.
3. Cost of materials supplied by contractor.
4. 10 per cent. profit on 1, 2 and 3.
5. Amount of oncost paid to sub-contractors.
6. 5 per cent. on sub-contracts.

There were to be no profits on parts supplied by the Ministry.

Various attempts were made to improve the Ministry's control of expenditure. In December, 1917, it was decided to keep a strict watch over extensions, to see if a firm were working at its utmost capacity on existing plant, whether dilution might help, or whether another firm could do the work. The extension of power supply was to be avoided as far as possible in the interests of economy, and building was not to continue when there was no hope of obtaining plant at the right time. The finance of housing was to be investigated, as it had sometimes happened that the houses cost more than the factory itself. On 1 January, 1918, a new procedure was adopted, with a view to obtaining fuller knowledge and better control of financial transactions.[2] Verbal "instructions to proceed" were to cease, and the formal channels of communication were to be used.

VI. Demands from the Navy and the Allies.

The Ministry of Munitions, in providing for the land service, was not the only competitor for the available sources of supply. The Navy and the Allies also had very urgent needs, before which those of the Army had sometimes to give way. The rivalry of the Navy was, of course, the most serious. The armament firms had made naval guns before the war, and had every reason to expect further orders after the war, but the future needs of the Army were problematic. In some cases, also, Admiralty work paid better than orders from the Ministry of Munitions, and the contractor was sometimes able to play off one authority against the other. Apart from this, it was not uncommon for competition between urgent needs almost to become chaos. For instance, at the end of 1915 it was reported from Barrow that "the speeding up of Admiralty work has made it almost impossible to get any machining done on howitzer work. This is not the first time this has happened, in fact it is a more or less continual struggle in the machine shops of Admiralty versus War Office work."[3]

It was impossible to meet all the demands of both Navy and Army, and capacity on which the Ministry had counted for very important work had sometimes to be given up to meet naval needs, notably in the period from the autumn of 1916 to the late spring of 1917. The Ministry found by experience that capacity thus given up was very difficult to

[1] 29 December, 1916. 94/G/5142. [2] D.D.G.(D.) 234.
[3] D.D.G.(D.) 144/G.

recover.[1] On the other hand, the Admiralty was able to help the Army by the suspension of work (as at the beginning of 1916) or the loan of guns, and capacity no longer required for naval shell was invaluable for the repair of land service guns in the spring of 1917.

Supplies to the Allies were another strain on British resources; political as well as purely military factors had to be considered, and guns were supplied to Russia on a considerable scale.

VII. The Success achieved in Supply.

The success of the Gun Department depended very largely on the relations between the Ministry and its four chief contractors. Apart from Woolwich the bulk of the engineering skill and technical knowledge of gun manufacture was concentrated in the management of those firms. Thus the most intimate relations were necessary, and the contractors had to be allowed very great freedom in order to encourage them in organising production and perfecting design, while personal intercourse smoothed away the difficulties and friction of formal procedure.

Mr. Lloyd George adopted the method of summoning the heads of the armament firms to conferences, explaining to them the needs or dangers of the moment, and enlisting their enthusiasm. The Ministry gun programme was considered at conferences with these firms in July, 1915, and in January, 1916, when the delay in deliveries was causing much anxiety, the Minister expressed to the armament makers his great regret that the hopes of the French would have to be disappointed, and explained that guns must be supplied immediately, without waiting for the niceties of the latest design.[2] "We had far better have a gun of the old type on the 5th April before action, than a gun of the most perfect type after action."

Conferences on a lesser scale were a constant feature. As noted above,[3] a regular weekly meeting was arranged to settle small points that might otherwise impede manufacture. Financial arrangements were often made at meetings with representatives of the firm concerned. Ministry officials visited the works, for instance, in the autumn of 1916 to explain the procedure for repair work and to settle details of finance.

Their experience of gun manufacture gave the armament firms a claim to careful hearing on points of design, material and inspection. Their suggestions were always considered and in many cases adopted, and they were also allowed to introduce small modifications during manufacture. On the whole their efficient organisation justified the liberty thus enjoyed, and the presence of resident "supervisors of progress," appointed by the Ministry about the beginning of 1916, helped to remove defects when they occurred.

Considerable tact was needed in dealing with the armament firms, who were sensitive both as to their dignity and their interests. In

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[1] D.M.R.S. 404.
[2] Hist. Rec./R/1200/17.
[3] *See* p. 62.

the latter connection they feared especially for their post-war trade. For instance, they took strong objection to a proposal made by the Ministry when arranging the finance of repair work that it should have access to their books, fearing that the officials who thus gained an inner knowledge of their affairs would use that knowledge against them in the service of other firms after the war.

Any delay in issuing drawings or in giving financial approval, or any hitch in the working of inter-departmental machinery, made the contractor sceptical of the urgency of the need that he was asked to meet. On the whole, however, the armament firms shewed immense enthusiasm for their work not only as a business undertaking, but as a contribution to the national cause. They took big financial risks, they lost private advantages and trade secrets, through the pooling of information, and accepted with a good grace the difficulties arising from unstable conditions and from the fluctuating demands of the war.

The achievements of the minor firms were in some ways even more remarkable. The Ministry took a great risk in using such firms for gun work, but the results were a triumph for its policy. By April, 1916, at least four hundred minor firms had been brought into the manufacture of gun and carriage parts. Breech mechanism work, a most intricate and difficult class of manufacture, had been carried out successfully by a firm which had made gas meters before the war.[1] The recruitment of firms who had never made gun forgings was soon justified by results, "A" tubes, and later on jackets, being also turned out in large numbers. Between June and December, 1917, the output of forgings had trebled.

A similar risk was taken in turning over the National Projectile Factories to gun work. Leeds and Nottingham filled a very serious gap in repair capacity, and later on the Nottingham Factory achieved a very creditable amount of new production. Before the war, such results from works new to gun making, and utilised only to meet a great emergency, would have been thought impossible. The standard reached may be illustrated by two examples. The Leeds Factory evolved a particularly good type of packing, and Messrs. Hick Hargreaves were found to be capable of giving valuable information about tools to so famous a firm as Messrs. Vickers.

The extent of the expansion arranged for by the Ministry is shown by the fact that in July, 1916, the manufacturing capacity available, compared with that of July, 1915, was roughly five times as great for 60-pdrs. and 4·5-in. howitzers, and twenty times as great for the 6-in., 8-in., 9·2-in. and 12-in. natures.[2]

The spirit in which all the firms worked was seen at its best in the spring of 1918, when the Minister telegraphed that owing to the urgent necessity for repairing the great losses that the British had suffered since 21 March, important work should continue without a break throughout the Easter holiday season. In reply, the Ministry received

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[1] D.D.G.(D.) 204.

[2] D.D.G.(D.)140. *See* also speech by Mr. Montagu in the House of Commons, 15 August. 1916. (*Parliamentary Debates* (1916) *H. of C.*, LXXXV, 1681.)

a shower of telegrams expressing the unanimous resolution of employees to remain at work and do all they could to support the Army in that time of crisis.

The Ministry had to organise production on a scale and at a rate that jettisoned all pre-war standards, and with declining assets in materials and labour, shipping and financial credit, had to meet an immense volume of demand, practically insatiable in amount and constantly changing in character. At no period of the war could the Department rest on its achievements; it was constantly called upon to solve some new problem. For the first two years of the war production was the imperative need. When stupendous efforts had been made to answer this call, the autumn of 1916 offered a double perplexity—the question of repair and the need for guns for merchant ships. Later on the demand for long-range artillery taxed to the utmost the ingenuity of design and the resources of supply. The solution of these problems, on which the safety of the Allied cause depended, was a triumph for British enthusiasm, knowledge and skill.

APPENDIX.

APPENDIX.

Deliveries to Service of Guns and Carriages from August, 1914 to December, 1918.

(a) New Guns and Carriages.

	1914		1915		1916		1917		1918		Total.	
	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages
13-pdr. (6 cwt.)	—	—	—	—	100	11	—	89	50	—	150	100
18-pdr.	43	—	2,629	2,381	1,492	1,724	2,091	1,002	3,653	1,819	9,908	6,926
4·5-in. Howitzer	40	—	561	553	1,008	1,046	562	568	1,213	1,270	3,384	3,437
60-pdr.	—	—	134	131	640	634	449	177	550	455	1,773	1,397
6-in. Gun	6	8	—	32	9	—	65	64	327	132	407	236
6-in. Howitzer	—	—	4	4	691	700	1,267	1,127	1,712	1,176	3,674	3,007
8-in. Howitzer	—	—	—	32	142	202	441	383	219	246	802	863
9·2-in. Gun	2	—	2	—	4	—	11	12	15	11	34	23
9·2-in. Howitzer	—	—	34	32	199	191	203	197	238	211	674	631
12-in. Gun	—	—	—	—	—	—	—	—	2	4	2	4
12-in. Howitzer	—	—	19	22	24	17	48	43	52	26	143	108
14-in. Gun	—	—	—	—	—	—	—	—	8	5	8	5
15-in. Howitzer	—	—	7	7	5	5	—	—	—	—	12	12
Total	91	8	3,390	3,194	4,314	4,530	5,137	3,662	8,039	5,355	20,971	16,749

Total 91 8 3,390 3,194 4,314 4,530

(*b*) REPAIRED GUNS AND CARRIAGES.

	1914		1915		1916		1917		1918		Total.	
	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages	Guns.	Carriages
13-pdr. (6 cwt.)	19	—	44	—	83	—	28	—	16	—	190	—
18-pdr.	9	—	5	—	200	12	1,627	464	2,116	571	3,957	1,047
4·5-in. Howitzer	—	—	—	—	18	8	214	110	711	176	943	294
4·7-in.	125	—	187	—	216	—	46	—	20	—	594	—
60-pdr.	—	—	20	—	90	—	347	43	836	149	293	192
6-in. Gun	3	—	8	—	29	1	73	—	104	2	217	3
6-in. Howitzer	25	—	66	—	24	7	213	225	622	290	950	522
8-in. Howitzer	—	—	36	—	59	—	67	42	251	58	413	100
9·2-in. Gun	—	—	—	—	1	—	20	—	10	—	31	—
9·2-in. Howitzer	—	—	—	—	—	—	67	29	251	40	318	69
12-in. Gun	—	—	—	—	—	—	1	—	5	—	6	—
12-in. Howitzer	—	—	—	—	—	—	11	2	19	1	30	3
15-in. Howitzer	—	—	—	—	—	—	1	—	—	—	1	—
Total	181	—	366	—	720	28	2,715	915	4,961	1,287	8,943	2,230

VOLUME X

THE SUPPLY OF MUNITIONS

PART II

GUN AMMUNITION: GENERAL

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CHAPTER I.

GUN AMMUNITION PROGRAMMES, JULY, 1915, TO MAY, 1918.

I.—The Relations of Gun Ammunition Programmes to Gun Programmes.

Demands for gun ammunition were governed by gun programmes and were calculated on the basis of a definite daily ration of ammunition for each gun in the field. The experience of the first six months of the war had swept away all previously accepted standards of expenditure of gun ammunition. The daily ration for each gun laid down in the early months of 1915 soon proved inadequate, and when the first gun ammunition programme of the Ministry of Munitions was drawn up the ration was increased. The ration was calculated at a flat rate throughout the year, but as expenditure in the winter months was lower, it was possible to accumulate reserves of ammunition which were available for the battle period, which was usually taken at about 32 weeks.

The experience gained in the Battle of the Somme, however, showed that the existing ration was inadequate, especially for the field gun. The expenditure of 18-pdr. shell during the summer fighting was far larger than had been expected, and was maintained continuously for the following reasons :—

(1) The barrage, largely composed of 18-pdrs., came into almost constant use to cover advancing troops, to cut wire, and to isolate enemy positions;

(2) The 18-pdr. guns were able to follow up an advance and come into action again almost immediately.

(3) When the enemy troops were out of permanent fortifications and in improvised trenches, shell holes, etc., 18-pdr. ammunition became once more effective.

In the programme of September, 1916, therefore, while the ration for all natures of gun was largely increased, the 18-pdr. ration was doubled and stood at 50 rounds per gun per day.

The tendency to a continuous increase in the ration was checked in the beginning of 1917 by the discovery that the provision of ammunition had outrun the provision of firing capacity. The lives of guns, when their rate of fire was no longer restricted by the need of hoarding ammunition, proved to be shorter than had been expected,

and the provision of extra gun bodies became more urgent than an increase in their daily ration of ammunition. An improvement in the supply of guns and the use of reduced charges did much to restore equilibrium, and the ration for most guns was once more increased in July, 1917, but as the shortage of 18-pdr. guns and of 9·2-in. howitzers had not yet been made up, the ration for those two weapons was slightly reduced. The increase in the ration for the 8-in. howitzer was partly due to the growing popularity of the latter on the new carriage which gave it traverse and put it more on a level with the 9·2-in. from the gunnery point of view, and partly to its superior mobility and the fact that its ammunition was easier to handle, being 33 per cent. lighter, round for round, than the 9·2-in. shell.[1]

The programme for 1919, which was adopted two months before the Armistice, showed little change in the ration, a slight increase in the daily provision for the 60-pdr. and 6-in. guns[2] being counterbalanced by a diminution in the heavy howitzer ration. It was hoped, however, that the larger number of guns in the field and their lengthened range would enable a concentration of fire to be obtained which would compensate for the fact that the daily ration remained practically stationary.

The following table shows the daily rations per gun which were laid down at various dates for the chief types of guns, forming the basis of the gun ammunit on programmes:—

	1915. Jan.	1915. June.	1916. June.	1916. Sept.	1917. July.	1918. Sept.
18-pdr.	17	25	25	50	40	38½
4·5-in. how.	17	20	25	36	38	35
60-pdr.	—	20	20	30	34	37½
6-in. how.	15	20	25	30	42	43½
6-in. gun	—	12	12	12	19	30
8-in. how.	15	15	25	30	33	28
9·2-in. how.	12	12	25	30	26	24½
12-in. how.	5	8	8	10	7½	7½
15-in. how.	—	5	6	7	4½	4

II.—The Proportion of Shrapnel and High Explosive Shell.

As has been seen, at the outbreak of the war the British army used very little high explosive shell, and one of the chief features of the first year of the war was the increasing demand for high explosive ammunition. The British Higher Command, however, retained its faith in

[1] *Review of Munitions Programme,* October, 1917, p. 11. Hist. Rec./R/1000/42.

[2] The ration for these guns had hitherto been limited by a fear of wearing out the guns. An improvement in supply removed this limiting factor. Letter from G.H.Q. to War Office, 8 September, 1918.

the efficacy of shrapnel shell for the 60-pdr. gun, the 4·7-in. gun, and above all for the field gun, and in spite of French experience and practice G.H.Q. asked that 50 per cent. of the ammunition for the 18-pdr. gun should be shrapnel. This was the proportion adopted as the basis of the first Ministry programmes, and the choice was fully justified by later experience.

General (later Sir John) Du Cane argued (18 January, 1916) that a larger proportion of 18-pdr. shrapnel ought to be supplied, since it had proved on the whole more useful. After the fighting in May and June, 1915, there had been an urgent demand for 18-pdr. H.E., but in the Battle of Loos an unexpectedly low proportion of high explosive shell had been used.

Various reasons were given in explanation[1] :—

(*a*) Owing to the shortage in the supply of H.E. this ammunition had been hoarded like gold. Artillery officers were not accustomed to its use and to a considerable extent were ignorant of its value. They were, therefore, inclined to use shrapnel in preference to H.E. in all cases of doubt.

(*b*) The accidents that had occurred, and the series of instructions restricting the use of H.E. to which they had led, had prejudiced many officers against this projectile.

(*c*) It had been demonstrated conclusively that shrapnel was the more effective projectile for wire-cutting. This necessitated a very heavy expenditure of shrapnel before the attack.

(*d*) Gas was used to prepare the attack on 25 September, and it was stated that H.E. shell would be liable to dissipate the gas cloud. The use of it was, therefore, forbidden before and after the assault. This necessitated a heavy expenditure of shrapnel for barrages.

(*e*) After the first assault there was a good deal of fighting in the open for two or three days, and there was a heavy expenditure of shrapnel for repelling counter-attacks.

General Du Cane pointed out that these considerations, combined with the fact that the enemy's defences became less vulnerable with the H.E. shells of field guns as time went on, would probably tend to keep the expenditure of 18-pdr. H.E. in preliminary bombardments, and in the severe engagements following them, well below the 50 per cent. asked for by G.H.Q. Though since the Battle of Loos the expenditure of H.E. had continued to rise in the ordinary day to day trench warfare, it had never exceeded 50 per cent., and it seemed reasonable to infer that over an extended period, including periods of severe fighting, the expenditure of 18-pdr. shrapnel would continue to exceed the expenditure of H.E.

The output of shrapnel would exceed the output of H.E. until April, 1916, and the accumulated stocks of shrapnel would considerably exceed those of H.E. at that date. General Du Cane, therefore, thought

[1] Memorandum by General Du Cane, 18 January, 1916. D.G.M.D./S/019.

it would be advisable to reduce the output of 18-pdr. H.E. from April onwards in favour of those natures which were more urgently needed. He thought that in discussing this question with the French at the forthcoming conference it should be borne in mind that they had practically discarded the use of shrapnel, and that they were, therefore, likely to express a preference for the projectiles that they used. In his opinion this should not be allowed to carry too much weight, as the British had considerable experience of offensive operations and must be allowed to draw their own conclusions. The French, for instance, proposed to devote an enormous number of 75-mm. H.E. projectiles to the task of wire-cutting, more than double the number of shells calculated by the British to be necessary for a similar task. This was because the British used shrapnel for wire-cutting, and had conclusively demonstrated its superiority for this purpose.[1]

On 16 February Mr. Lloyd George wrote to General Du Cane as follows[2] :—

> " We ought to have a conference at an early date as to the functions of the 18-pdr. H.E. At the present moment we are ordering enormous quantities of this, and they are coming in at a great rate. By and by we shall be overwhelmed with the supply. The French use it for destroying barbed wire as well as for counter-attacks. I understand from you that our 18-pdr. H.E. shell is not effective for either of these purposes. If that be so, what are we ordering it for ? Either we ought to cease ordering it, or the capacity of the shell ought immediately to be increased in order to make it effective.
>
> " Perhaps the improvement in the detonation of the shell which you are effecting might alter your views about its utility. Will you please let me have your views on the subject."

In reply General Du Cane submitted a memorandum with an explanatory table showing the expenditure of 18-pdr. H.E. and 18-pdr. shrapnel from September, 1915, onwards :—

Month.	S.	Percentage of Total.	H.E.	Percentage of Total.
September	487,789	88	65,937	12
October	406,721	72	163,367	28
November	311,008	88	42,341	12
December	277,207	74	100,155	26
January	263,295	60	178,329	40

He pointed out that for various reasons[3] the percentage of H.E. used was very low during the period of active operations in September. He thought that the percentage of 18-pdr. H.E. shell would probably

[1] 18 January, 1916. D.G.M.D./S/019.
[2] D.D.G.A./13204.
[3] See above, p. 3.

not rise above 50 per cent. in times of inactivity, and would fall again during periods of active operations when there was fighting in the open.

The value of the existing 18-pdr. H.E. shell was confined to its destructive effect when burst on graze, and to man-killing effect when burst after ricochet. Its effect was not great for either purpose, but it could be greatly improved by better detonation which was to be expected with the improved fuse and still further improved by adopting a shell of greater capacity. The Ordnance Committee had designed a new shell with a bursting charge of 21 oz. as against 13 oz. in the existing shell, which would be a very considerable improvement, but he pointed out that the bursting charge of the French H.E. shell was 29 oz. for a much lighter shell, this larger bursting charge being possible because the French hardened the steel and their fuse and gaine occupied less space in the head of the shell.

Compared with the French 75-mm. H.E. which gave instantaneous effect on graze or burst very soon after ricochet, the British 18-pdr. H.E. shell that buried themselves on graze or burst from 10 to 15 ft. in the air after ricochet were comparatively valueless for wire-cutting.

There was a very serious shortage of 13-pdr. shrapnel.[1] The requirement was 25 rounds per gun per day, of which 50 per cent. should be shrapnel, but the estimated output of 13-pdr. shrapnel amounted to only 1 round per gun per day in January, 1½ in March, 3½ in April, and 7½ in June.[2] This did not include possible consignments from India, but in view of the campaign in Mesopotamia, these could not be relied upon.

If this ammunition were used only by the Horse Artillery the situation could be viewed with equanimity, as Horse Artillery were seldom employed in winter trench warfare, and supplies could accumulate. Thirteen-pounder shells were, however, used by anti-aircraft guns, and when the Spring came there would be heavy expenditure and the provision of 13-pdr. shrapnel would be inadequate.

On 31 January, Mr. (later Sir Glynn) West reported that he had made arrangements for a number of firms to produce 13-pdr. instead of 18-pdr. shell, and he hoped that the shortage would be quite overcome by March.

At the same time (18 January) General Du Cane emphasised the importance of an adequate supply of shrapnel for the 60-pdr., 4·7-in. and 6-in. guns, which the Commander-in-Chief had asked for on 8 February.[3] Fifty per cent. of the total shell supply for these guns had been asked for in shrapnel, but General Du Cane thought that the provision was below requirements for the 60-pdr. and quite inadequate for the 4·7-in. gun, which was likely to remain in the field longer than had been anticipated.

[1] 18 January, 1916. D.G.M.D./S/019.
[2] *Ibid.*
[3] C.R.4428.

The fact that it had been possible to supply a large British force, which during the second Battle of Ypres had fought for three weeks or more east of the town, with food and ammunition coming by the main road leading east and west through the town, was primarily due to the exclusive use by the Germans of H.E. projectiles for shelling our communications at night. During the fighting at Festubert in June, and again at Loos, a successful feature of British artillery tactics was the shelling of cross roads, roads and communication trenches at night with shrapnel from long range guns to prevent the provisioning and relief of troops in the front line.

A table was given to show the position as to supplies of ammunition for the 60-pdr. and 4·7-in. guns.

Rounds per Gun per Day.

	Required	Provision.					
		Jan.	Feb.	March.	April.	May.	June.
60-pdr. shrapnel	10	6	6	7	8	8	8
60-pdr. H.E.	10	7	9	11	13	15	16
4·7-in. shrapnel	7½	1	1	1½	2	3	5½
4·7-in. H.E.	7½	4	5	7	9	11	11½

Long-range shrapnel fire from heavy guns was also essential for counter battery work and for attacking the enemy's observation balloons.

Shrapnel for the 6-in. gun had been asked for in July, 1915, but it was only beginning to be supplied at this date (18 January), and General Du Cane had seen no estimate of output.

Colonel (later Sir Arthur) Lee agreed that the position with regard to shrapnel for 60-pdr., 4·7-in. and 6-in. guns was very unsatisfactory, and that a special effort should be made to increase the production of these shells.[1]

Mr. West reported on 31 January that there was a large stock of 60-pdr. shrapnel at Woolwich—over 19,000 empty and 64,000 filled—and that he was doing everything he could to press forward further supplies and to increase the output of 4·7-in. and 6-in. With reference to 4·7-in. shrapnel, the Ministry had not been informed until 14 September, 1915, that the 4·7-in. guns were not to be withdrawn, and negotiations for the manufacture of these shells therefore did not begin until that date. Further, the design of the 6-in. shrapnel had not been issued until the beginning of 1916. Fortunately manufacture had been carried on in anticipation, but it was only by reason of this action that it had been possible to make deliveries at an early date.

[1] 19 January, 1916. D.G.M.D./S/019.

General Du Cane's view of the importance of shrapnel ammunition was supported by a letter from G.H.Q. (19 April), which stated that throughout the Army there was a demand for a large proportion of shrapnel for the 13-pdr. and 18-pdr. guns, particularly as a large number of guns and howitzers of a heavier nature had become available. If possible 75 per cent. of shrapnel should be supplied or, failing this, the existing proportion (70 per cent. shrapnel to 30 per cent. H.E.) should be maintained. The assumption that H.E. was as effective for wire-cutting as shrapnel, which had been the basis of the 50 per cent. demand, had been proved wrong.[1]

Efforts were made to meet this demand, and when the output of 18-pdr. H.E. was cut down in May, 1916, that of shrapnel was maintained.[2] It was impossible, however, to give the Army the amount of shrapnel it required, and a letter from G.H.Q. (23–27 June) stated that in view of the improvement recently effected in the detonation of high explosive shell the proportion might be increased to 60 per cent. shrapnel and 40 per cent. H.E., the shrapnel shortage being made good by an increase of H.E. until the full requirement could be met.[3]

A few days later, however (29 June), the Ministry reported that it would be impossible to obtain enough high tensile steel for even 60 per cent. of shrapnel shell, unless a design could be approved for 24 ton steel, which would reduce the number of bullets in the shell by one quarter, and materially reduce its efficiency. On 31 August G.H.Q. agreed, in view of the difficulty of getting suitable steel, to accept 50 per cent. of shrapnel.[4]

When, in September, 1916, the ration for 18-pdr. guns was raised to 50 rounds a day the Ministry urged that as much H.E. as possible should be used as there were large stocks in existence. Further, H.E. was easier to manufacture and the steel for shrapnel was very short.

The armies in France, however, had a marked preference for shrapnel ammunition, especially for offensive purposes, as it did not make the ground impassable with shell holes, and continued to ask for it in the proportion of 70 to 30. They would have liked 75 per cent. shrapnel to 25 per cent. H.E., but owing to tonnage restrictions there was a shortage of lead (which had to be imported from Australia), and the Ministry only undertook to supply it in the proportion of 70 to 30.[5] The introduction of chemical shell for the 18-pdr. gun led to a variation, and in August, 1918, the ration asked for by the War Office was 40 per cent. H.E., 40 per cent. shrapnel, and 20 per cent. chemical,[6] and this remained in force until the end of the war.

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[1] D.M.R.S. 372.
[2] D.M.R.S. 390.
[3] *Ibid.*
[4] D.M.R.S.290.
[5] Conference at G.H.Q., 19 March, 1918. Ministry to War Office, 11 April. (D.M.R.S.535.)
[6] HIST. REC./R/1000/63.

III.—Ammunition Programmes, July to December, 1915, and their Modification in the Spring of 1916.

The evolution of the gun programmes of 1915 has already been described in some detail elsewhere,[1] and as the ammunition programmes were governed by the gun programmes, the number of rounds required per week being determined by the number of guns coming forward and the daily ration of ammunition required for them, it will be sufficient here to give the programmes of 1915 in tabular form.[2] The maximum weekly output of field gun ammunition contemplated under the first July programme (programme A) was 58,800 per week, which was to be reached in March, 1916. Programme B raised the maximum to 340,000 a week, and programme C, which was adopted in September, asked for a maximum of 767,000 rounds for the field gun, half being H.E. and half shrapnel.[3] The maximum for the 6-in. howitzers under programmes A, B and C was 57,820, 56,000 and 126,000 respectively.[4]

On 1 January, 1916, the Army Council asked for information as to the probable weekly output of ammunition up to the end of April, and in reply the Ministry sent two estimates, estimate A and estimate B, the former being "on a conservative basis," while the latter was more hopeful. It was suggested that the War Office should use estimate A when taking into consideration the possibility of military operations, and that estimate B should be used as the basis on which the War Office should provide transport facilities, etc. The former estimate was "not a guaranteed figure" as there were many matters of design just passing the experimental stage, and there was the possibility of delay both in this respect and also in the starting of the new filling factories. A heavy discount, however, had been allowed off the estimated output of the latter, and estimate A represented the number of complete rounds the Ministry expected to be able to issue "if matters went reasonably well."[5]

The average weekly issues anticipated for the month of May under these two estimates for delivery to France and the Mediterranean, excluding despatches to Russia, were as follows :—

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[1] Vol. X, Part I.

[2] The programmes from 1915 to 1918 are summarised in the Appendix.

[3] D.M.R.S. 33 and 50.

[4] For details see Appendix.

[5] The actual production for January fell far short of estimate A, especially with regard to 18-pdr. H.E. shell. Mr. Lloyd George said it had "miserably failed in several natures," and that revised estimates for February, March, April and May must be produced. "If I mislead the army both I and my advisers deserve to be court-martialled." Estimate A was criticised by Colonel Lee as "superficial and highly speculative." Mr. Layton's reply to these criticisms was given in a minute to the Minister, 18 February, 1916. C.R. 3008.

Nature.	Estimate A.	Estimate B.
18-pdr. shrapnel	300,000	330,000
18-pdr. H.E.	350,000	375,000
4·5-in. H.E.	75,000	105,000
60-pdr. shrapnel	12,000	18,000
60-pdr. H.E.	25,000	30,000
6-in. H.E.	40,000	51,000
8-in. H.E.	8,500	11,000
9·2-in.	5,000	7,500
12-in.	1,200	1,575
15-in.	250	270
2·75-in. shrapnel	3,500	3,950
2·75-in. H.E.	4,000	6,000
13-pdr. shrapnel	9,000	12,800
13-pdr. H.E.	20,000	24,600
4·7-in. shrapnel	2,000	3,150
4·7-in. H.E.	6,000	5,100
5-in. how.	12,000	14,900

The Army Council, when acknowledging these estimates (25 January, 1916),[1] stated that they would like to see shrapnel and H.E. ammunition for the 13-pdr. gun supplied in equal quantities (which meant a large increase in the orders for shrapnel), and that they were prepared to accept less 5-in. ammunition in order to increase the supply of 4·7-in., 6-in., and 60-pdr. ammunition (for which more shrapnel in particular was urgently wanted), and less 12-in. ammunition in order to increase the supply of 9·2-in. howitzer ammunition. The Army Council pointed out that the amount of 4·5-in. ammunition suggested in estimate A was quite inadequate as it would only provide about 9 rounds per gun a day in May, whereas 20 rounds per gun had been asked for.

Before this, however (5 January), the Army Council had suggested that, in order to avoid unnecessary expense, the orders for guns should be reduced, and that the ammunition requirements should be modified so that there should be no increase beyond the following monthly deliveries :—

18-pdr.	2,000,000
4·5-in. how.	672,000
60-pdr. gun	306,000
6-in. how.	336,000
8-in. how.	100,000
9·2-in.	58,000
12-in.	11,500
15-in.	1,800

Mr. Lloyd George was not prepared to accept this reduction. The matter was submitted to the Cabinet Committee on the Co-ordination of Military and Financial Effort and decided in his favour, the committee being " satisfied that the orders placed by the Ministry in excess of War Office requirements were necessary in order to secure a very large output in the early part of 1916." A letter to the War Office

[1] D.M.R.S. 310.

(14 February)[1] pointed out that although Mr. Lloyd George had always understood that the figures given to him by the War Office represented the minimum amount of ammunition required, the War Office letter of 5 January suggested that the new figures were the maximum amount. If the Army Council wished the output of completed ammunition in May, June and July to be limited to these figures the responsibility for the decision would rest with them, subject to the general approval of the War Committee of the Cabinet. He pointed out that up to the present the experience of each successive battle had shown that every estimate of requirements formulated either by the French or the British armies had been exceeded. The estimate of output forwarded by the Ministry on 17 January went beyond War Office requirements for certain natures, but it was assumed to be desirable to expand output as much as possible in order to make good previous deficiencies and accumulate a stock of ammunition as soon as possible. Even if the estimate was realised in full, the accumulation of ammunition would not be in excess of the requirements furnished by the Commander-in-Chief to the Minister on the occasion of his recent visit to France, and would be considerably less than the amount asked for by the French for the length of front on which the Commander-in-Chief had planned to attack. Finally, the Army Council was asked "if it foresaw any difficulty either in the way of transport or storage in taking delivery of the amount of ammunition that had been indicated."

The Army Council accepted the situation (28 February).[2] As they understood that the Cabinet Committee was satisfied that orders in excess of the War Office requirements were necessary, they would leave the matter where it was for the present, especially as they were satisfied that it would be some months before the delivery of the monthly output—with the exception of the 18-pdr.—would be completed, and even in the case of 18-pdr. ammunition there would be considerable arrears to work off.

In a memorandum of 18 January, 1916,[3] General Du Cane had emphasised the fact that the shells available for British 4·5-in. howitzers would be very short, owing to the arrangements made to supply 300 4·5-in. howitzers to the Russians, with a full complement of ammunition on the scale of 20 rounds per gun per day, beginning in January. According to Ministry estimates of delivery, instead of the 20 rounds a day required for British 4·5-in. howitzers, there would only be 4 rounds per gun per day available in January, 5 in February, 7 in March, 10 in April, 15 in May, and 15 in June. Thus we should in March be giving 180,000 rounds to the Russians for 300 guns and keeping for ourselves only 97,000 rounds for 440 guns. Whatever might be the enhanced value of the bigger natures under the conditions prevailing on the Western front, it still remained a fact that an inadequate supply of ammunition for the 4·5-in. howitzers would seriously cripple the offensive power of the army, and General Du Cane hoped that 4·5-in. H.E. would not be set aside for the Russians on the very liberal

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[1] D.M.R.S. 214. [2] 57/3/4905, in D.M.R.S. 214. [3] D.G.M.D./S/019.

scale contemplated, but that at least half of it would be issued to British troops. There was a stock of 60,000 rounds of 4·5-in. shrapnel, which might be put aside for the Russians as a make-weight. The output of 4·5-in. shrapnel had been in excess of requirements, and G.H.Q. had expressed its willingness to forgo this projectile altogether if the output of ammunition of more important natures would be facilitated thereby.

Colonel Lee concurred with General Du Cane's suggestion "to the extent at any rate that we and the Russians should share alike in the allocation of any available 4·5-in. ammunition," and Mr. Lloyd George on 20 January decided that the supply of ammunition to the Russians should be based on the general proportion of deliveries per gun at that date.[1] He added: "I cannot think the Russians will complain as long as they receive equal treatment with our own army."

On 31 January Mr. West was able to report an improved position with regard to the supply of 4·5-in. ammunition. On 15 January there was a stock of over 524,000 empty and over 100,000 filled shell. The average output for the last three weeks had been over 100,000, which more than met the requirements. The revised list of what was to be supplied to the Russians also improved the situation and it was chiefly a matter of pushing forward filling arrangements.

At the same time General Du Cane urged that every effort should be made to increase the output of ammunition for 6-in., 8-in., and 9·2-in. howitzers. The supply of ammunition in rounds per gun per day for these howitzers would meet requirements by April, but the number of these guns in the field would be considerably short of requirements. This shortage of guns could be compensated for to some extent by an increase in the ammunition supply.

> "If the ammunition supply is good, and the initiative is clearly with us, a high proportion of the available heavy guns and howitzers can be concentrated for the offensive and its scope enlarged thereby. If, as occurred last Spring, we still have to reckon with the possibility of being forestalled by a hostile offensive, the heavy guns and howitzers must remain, to a great extent, dispersed along the front, and a shortage of heavy guns means a limitation to the scope of the attack. The requirements in ammunition formulated by G.H.Q. were based on the conception of a considerable but not complete concentration of the available heavy guns. The more ammunition available the more sustained could be the offensive, whatever its scope; but it was necessary that the supply of the different natures should be correctly balanced."

Mr. West stated that very special efforts were being made to increase the output of 8-in. and 9·2-in. H.E. shells. There had been a satisfactory increase in the output of 6-in. H.E., which had risen from 3,997 in the week ending 8 January to 8,550 in the week ending 22 January, excluding Ordnance Factory deliveries, which had also been more satisfactory.[2]

[1] D.G.M.D./S/019.

[2] 31 January, 1916. D.G.M.D./S/019.

General Du Cane drew attention to the fact that the probable supply of ammunition for the 12-in. howitzer would be a little short of requirements from February onwards, while for the 15-in. howitzer the shortage would be greater; but, on the other hand, the requirements of G.H.Q. in howitzers of these natures would actually be exceeded.

The next considerable modification in the gun ammunition programme was that adopted in June, 1916, which was in a special sense a Ministry programme, inasmuch as it proposed to provide heavy ammunition in the Autumn of 1916 and Spring of 1917 beyond War Office requirements, in order to give an adequate supply for the heavy guns ordered in excess of War Office demands. The new programme also gave a figure of 700,000 a week for 18-pdr. shell, which exceeded the maximum previously asked for by the War Office, but from a memorandum handed to Mr. Lloyd George by Sir Douglas Haig in January, dealing with the anticipated expenditure of ammunition during an offensive, it was evident that continuous operations on the scale anticipated could not be obtained without an output approximating to 700,000 a week.[1]

The experience gained in the first month of the Battle of the Somme showed that expenditure had exceeded issues in all natures from 18-pdr. upwards, excluding 4·7-in., 8-in., and 9·2-in.[2] The expenditure of the two latter in the preliminary bombardment had been heavy, but owing to the fact that special efforts had been made to send out large quantities of this shell, reserves had considerably increased. The most serious features were the fact that expenditure of 18-pdr. and 6-in. had much exceeded expectations. At the then rate of expenditure stocks of the latter would be reduced to 100,000 rounds by the end of August, but as a considerable increase of output was expected in September the situation would be restored quickly. The 18-pdr. situation, however, was more difficult. The field gun had been firing at the rate of nearly 1,000,000 rounds a week, and as there was a prospect that expenditure would continue at this level, Mr. Montagu urged that the 18-pdr. programme should be raised from 700,000 to 1,000,000 rounds a week.

This suggestion was borne out by experience on the field, and on 26 August G.H.Q. asked that consignments of 18-pdr. ammunition should be increased to 130,000 rounds a day, or to 150,000 a day, if the latter amount could be produced without prejudicing other supplies.[3]

On 6 September, Mr. Montagu again pointed out that while the existing programme for heavy ammunition provided for 480,000 rounds a week, which was three times the average amount fired weekly on the Somme—less than 150,000 rounds from 4·7-in. upwards—the expenditure of light shell was greatly in excess of issues. The October programme, therefore, as will be seen below, increased the requirement for field gun ammunition still further.[4]

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[1] Letter to War Office, 16 June, 1916 (D.M.R.S. 390).
[2] Letter from Mr. Montagu to Mr. Lloyd George, 5 August, 1916 (D.M.R.S. 390).
[3] Letter from G.H.Q. to War Office, 26 August, 1916 (D.M.R.S. 390).
[4] D.M.R.S. 390.

IV.—The Programme of October, 1916.

The programme of October, 1916, was the result of the experience gained on the Somme, which proved that the existing rations of ammunition were inadequate. On 23 September the Commander-in-Chief in France recommended a scale of output of ammunition, calculated in rounds per gun per day, based on the actual expenditure during a period of two and a half months. The gun ration was raised for nearly all natures, the most striking change being in the ration for the 18-pdr. gun, which was raised from 25 rounds to 50 rounds per gun per day.[1] Later, about 9 October, in consequence of a considerable increase in the demand for 6-in. howitzers and of a further raising of the gun ration, the War Office put forward a revised demand which became the basis of the 1917 shell programme.

In order to show the extent to which this programme surpassed all previous demands the figures for the more important natures are here compared :—

COMPARISON OF JULY, 1916, AND OCTOBER, 1916, GUN AMMUNITION PROGRAMMES.
(Weekly requirements.)

	July, 1916. Rounds.	October, 1916. Rounds.	July, 1916. Steel.	October 1916. Steel.	Copper Driving Bands. July.	Copper Driving Bands. October.
			Tons.	Tons.	Tons.	Tons.
18-pdr. H.E... ..	280,000	600,000	3,640	7,800	156	268
S.	420,000	600,000	2,520	3,600		
13-pdr. H.E... ..	36,440	36,440	310	310	12	12
S.	19,660	19,660	80	80		
4·5-in. H.E.	248,550	314,000	5,965	7,560	135	176
		5,000 (inc.)		65		
4·7-in. H.E... ..	6,440	10,000	225	350	7	11
S.	6,440	10,000	97	150		
60-pdr. H.E... ..	49,000	63,500	2,060	2,600	71	92
S.	49,000	63,500	1,030	1,330		
6-in. How.	204,000	295,000	13,900	20,310	137	198
6-in. Gun H.E. ...	8,100	8,000	575	565	26	26
S.	8,100	8,000	292	290		
8-in. How.	80,000	80,000	10,760	10,760	184	184
9·2 in. How... ..	63,500	63,000	11,540	11,540	264	264
12-in. How... ..	5,000	5,000	2,450	2,450	40	40
15-in. How... ..	510	510	525	525	4	4
3-in. Univ. H.E. ..	10,000	10,000	110	110	3	3
S.	6,000	6,000	30	30		
3·7-in. H.E... ..	5,040	5,040	85	85		
2·75-in. H.E... ..	12,000	12,000	100	110	2	2
S.	12,000	12,000	60	60		
Totals	1,529,730	2,226,610	56,364	70,680	1,041†	1,280†
Margins.. ..			15%	15%		
Grand Total ..			64,800	81,400		

Brass for Primers, Fuses, Cartridge Cases, etc.	July. Tons.	October. Tons.
Primers.	305	480
Tubes. F. tubes	41	50
V.S.P. tubes	2	2·5
Fuses. Shr. 80 Mk. V.	225	264
Shr. 80 Mk. VII	586	688
H.E. 101	1,145	1,800
106	701	795
Nose Bushes.	253	310
Fuse Sockets.	254	347
Central Tubes.	117	164
Cartridge Cases.	1,268	1,985
Totals	4,900	6,888
Margins	*Varying from 5 to 25%	
Grand Total	5,185	7,305

† The weight given is that of the rough copper band. About twice the amount of metal was required to produce the rough band, but no estimate was then available as to the extent to which the surplus metal could be used again.

* In the case of primers and tubes allowance had been made for the necessary proportion of spares. For fuses, 5 per cent. had been added for faulty parts, and for cartridge cases 10 per cent., no allowance being made for salved cases. It was assumed for the calculation that each case could be used three times.

[1] O.B./796/A. in D.M.R.S. 440; D.M.R.S. 390.

The chief feature of this programme was the very large demand for 18-pdr. ammunition, which came at a time when the production of shell of this nature had been reduced to a very low level. Huge stocks of this shell had been accumulated in the summer of 1916 and production had therefore been curtailed, the actual deliveries from 1 October to 31 December, 1916, averaging only 122,771 a week of high explosive shell, and 367,971 a week of shrapnel shell.

But, as has been seen, the expenditure of 18-pdr. ammunition during the Somme offensive had so greatly exceeded production that the stock of 6,000,000 18-pdr. shell in hand when the battles started, had been reduced to 2,000,000 by the beginning of October. In order to begin the Spring campaign of 1917 with a reserve of 10,000,000, the Ministry thought that 1,200,000 rounds per week was the absolute minimum production which should be maintained throughout the Winter.[1]

The programme for 18-pdr. ammunition put forward by the War Office on 23 and 29 September,[2] was only 1,000,000 rounds a week for France and 94,000 for other theatres of war. The Ministry questioned whether this increase in the 18-pdr. programme was sufficient in view of the large proportionate increase in the demand for the heavier natures, and on 4 October put its point of view before the Army Council as follows[3] :—

> " The Minister notes that Sir Douglas Haig asks for 1,000,000 rounds of 18-pdr. per week in France, a figure which approximately equals recent expenditure. The Minister, therefore, concludes that in spite of the possible extension of the scope of operations in 1917, and the fact that expenditure of 18-pdr. ammunition on fronts outside the sphere of offensive operations has been strictly curtailed during the last few months, the Army does not anticipate any increase in the expenditure of this nature of ammunition. In this connection it may be of interest to recall that, according to information recently supplied to Mr. Montagu by M. Thomas, the ultimate programme of French production shows 214 rounds of field gun ammunition for every 100 rounds of heavier natures—the expenditure on the whole French front during the last three months having been 389 rounds of field gun ammuntion per 100 rounds of other natures.
>
> " The present programme put before the Minister of Munitions allows for 143 rounds of 18-pdr. per 100 rounds of heavier natures as against an expenditure of 273 rounds of 18-pdr. per 100 rounds of other natures in the last three months.
>
> " The proposed new maximum represents an increase of 8 per cent. in the case of 18-pdr. over recent expenditure and of 100 per cent. in the case of all other natures.

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[1] D.M.R.S. 390, D.M.R.S. 440.
[2] O.B./796/A. ; 57/3/5106 ; 121/Stores/0496.
[3] D.M.R.S. 390.

In view of these considerations, the Minister considers that it would be prudent to have in hand some reserve capacity against the possibility of a further increase in the demand for field gun ammunition at a later date. Financial pressure and the demand for men, however, in conjunction with the great strain which will be imposed on our resources by the attempt to meet the new demand for heavy ammunition, will make it more difficult every month for our supplies of ammunition to retain any elasticity, and the Minister desires to represent to the Army Council that the allocation of our resources which is now made is likely to be final as far as 1917 is concerned. But Mr. Montagu does not wish at this late stage to take the responsibility of setting aside reserve capacity for the production of particular munitions, and I am, therefore, to ask whether, in the opinion of the Army Council, he would be justified in assuming that no further increase will be made in the demand for 18-pdr. ammunition, and that he can with safety hypothecate all possible resources, both at home and abroad, to heavier natures."

On 7 October the Army Council raised the demand for 18-pdr. ammunition for theatres of war outside France to 200,000 a week, making the total weekly requirement for this nature 1,200,000 a week.[1]

From the supply point of view this large programme presented certain difficulties. Sir Glynn West was reported to be "quite undaunted by its dimensions," but it was anticipated that there might be considerable difficulty in obtaining enough propellant to meet the programme.[2]

The whole question was referred to the Advisory Committee, which was asked on 13 October to investigate and report to the Minister on the following points :—

" (*a*) Whether the materials required for the new Gun Ammunition Programme are obtainable.

" (*b*) What proportion of these materials can be obtained in this country, in Canada or the U.S.A. ?

(*c*) Whether the procuring of the quantities required for gun ammunition will involve any restriction of the production of other essential articles.

" (*d*) Whether the necessary machining capacity for carrying out the programme is available, and whether the proportion machined in this country could suitably be increased, with special reference to man-power."

After making investigations and consulting the heads of the departments concerned, the Advisory Committee were able to report that if large quantities of shell were bought in the United States and in Canada the new programme could be met, provided that the labour required was obtainable.

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[1] 57/3/5106.
[2] 9 October, 1916, D.M.R.S. 440 ; see Vol. X, Part IV, Chap. VII.

Their general report was in the following terms :—

(1) In reply to (*a*) they were of opinion that the materials required for the new Gun Ammunition Programme were obtainable, provided their recommendations as to labour could be met.

(2) As regards (*b*) they, in consultation with the departments concerned, had made recommendations as to supplies from this country, Canada, and the United States of America.

(3) As regards (*c*), the supply of materials and the manufacturing and labour capacity of the country would be strained to the utmost in meeting the new programme, and therefore the production of articles other than munitions would necessarily be restricted.

(4) As regards (*d*), the Committee were of opinion that machining capacity for carrying out the new programme could be made available. Extensions of plant necessary were dealt with in the recommendations.

(5) The Committee emphasised the uncertainty of the labour position in regard to their recommendations, and stated that the carrying out of the new programme from a supply point of view was entirely dependent upon the necessary labour being forthcoming.

This programme, which involved, as has been seen, dependence to a serious extent on overseas supplies, was endorsed by the Minister. An effort was, however, made to get the War Office to reduce its demand for 6-in. howitzer shell, in order to provide a margin of shell-making capacity which might serve as an insurance on the whole programme. In a letter from the Minister to the Secretary of State for War, dated 31 October,[1] the War Office was informed that if the figures put forward were to be reached supplies would be taxed to the utmost limit in many directions, especially in the cases of shell steel, copper, and propellant. A new factory for propellant would have to be built, which would require from 15,000 to 20,000 men for constructional work and 6,000 workpeople (most of whom would be women) for its operation. Another large factory for the raw material of explosives would also be required, which would need from 900 to 1,000 men for its operation.

> " But even with this added capacity, I am to point out that in these and some other directions, not only will there be no margin to allow for failures of output or accidents of any kind, or for new urgent unforeseen demands, but it will also be necessary to make a careful division of the world's resources between ourselves and our Allies. In these circumstances it would greatly simplify the task of arranging the whole programme, strengthen the Minister's hands in dealing with manufacturers and particularly with American producers of material, and at the same time

[1] D.M.R.S. 440.

provide a margin for insurance against accidents and unforeseen demands on the whole programme, if the requirements for 6-in. howitzer ammunition could be reduced by 50,000 a week, and I am to enquire whether military considerations permit this suggestion to be entertained. In this connection Mr. Montagu ventures to remind the Army Council that the demand for this nature of ammunition is based in the light of recent experience, on a ration of 30 rounds per howitzer per day, and to suggest that when the establishment of these howitzers is increased to four times the present number, a somewhat lower daily ration might prove to be adequate.

"Finally, I am directed by Mr. Montagu to urge with the utmost emphasis upon the attention of the Army Council that the fulfilment of the programme, even if modified in the way proposed, depends on the supplies of labour in munitions factories being maintained and increased, especially in connection with the manufacture of steel, copper bands, brass rod and stampings, propellants and high explosives, and the constructional work necessitated by the provision of these materials. The supply of labour at the present is insufficient to produce the output of ammunition asked for by the Army Council in July of this year, and unless the requirements in this respect as well as the additional numbers needed are forthcoming, the new programme cannot be met. Mr. Montagu, therefore, wishes me to add that he must rely in a very large measure upon the co-operation and active assistance of the Army Council in this matter if the output needed in 1917 is to be obtained."[1]

The War Office replied (14 December) that the Commander-in-Chief was reluctant to reduce the ration for the 6-in. howitzer below 30 rounds a day and the figure therefore remained at 295,000 per week.[2]

As there were large stocks of 12-in. and 15-in. ammunition in existence and it was not proposed to manufacture any more 15-in. howitzers to replace those then in the field, the Ministry asked the Army Council to sanction a reduction in the programme of ammunition required for these weapons (29 November), in order to economise steel and high explosive. The Army Council agreed ; the requirement for 15-in. howitzer ammunition was reduced to 300 a week and for 12-in. howitzer ammunition to 4,000 a week. Owing to the large stock of the latter in hand (90,000), it was later decided that a filling programme of 2,000 a week would meet the demand.[3]

The programme was an ultimate programme in the sense that it was designed to supply a full daily ration of ammunition for a full establishment of guns. The date at which the programme was to mature depended on the rate at which guns on the appropriate scale were delivered to the Army. It was hoped that the Army would be

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[1] D.M.R.S. 440. [2] *Ibid.* [3] *Ibid.*

fully equipped with guns by the end of June, 1917, and arrangements were to be made for the output of gun ammunition to reach its maximum by that date. No exact curve could yet be drawn of the stages by which the existing manufacturing capacity could be worked up to the desired maximum, or even of the rate at which issues to the Army of completed ammunition would increase between January and June. The latter depended on gun deliveries, the former on separate estimates of the increase in the output of steel, shell, shell components, explosives and propellant which were not fully worked out when the Advisory Committee made its recommendations in November. There was one exception—the 18-pdr. programme. The Army was already fully equipped with 18-pdr. guns, and the issue of 18-pdr. gun ammunition was to start at once at the rate of 1,200,000 a week. This meant drawing on the reserve stock of 20,000,000 shell, of which 15,000,000 were H.E., and creating a serious position with regard to shrapnel.[1]

The programme put forward in October, 1916, was a net programme, that is to say, the Ministry limited itself as it had done in July to meeting the figures put forward by the War Office. On previous occasions the Ministry had added 20 per cent. to the War Office figures in order to provide a margin for insurance against contingencies. The formidable nature of this new programme made it necessary to abandon this margin system and work to the net requirements, and Sir Glynn West pointed out that the only thing now left by way of a margin was whether more could be got out of the plants than he was estimating for.[2]

The question of reserve stocks, therefore, became specially important. Mr. (later Sir James) Stevenson was of the opinion that the Minister should be informed that in making its recommendations the Advisory Committee had not been able to take into consideration the extent to which reserve stocks would be drawn upon in fulfilling the programme, and that it was essential that a decision should be reached as to what stock of each store it was desirable to keep in reserve.[3] In order to minimise the danger of abandoning the margin, each department was informed that it must provide reasonable insurance on its own account when making estimates of output and delivery.[4]

When putting forward their shell manufacturing programme, the Advisory Committee made the general recommendation that requirements for offensive warfare should have precedence of requirements for defensive warfare. Before demanding materials in which they had not hitherto dealt, departments were first to enquire whether their demand was likely to upset existing requirements. Great difficulty had been caused by the Trench Warfare Supply Department placing orders for silk necklets for the protection of bombers, and thereby jeopardising the supply of silk for 18-pdr. cartridge cases. On 31 November the Minister ordered that an Office Instruction should be

[1] See Vol. X, Part III.
[2] A.C. 2.
[3] *Ibid.*
[4] A.C. 71.

circulated to carry out the recommendation of the Advisory Committee. On the same date, Sir Alexander Roger and Colonel Milman were instructed to prepare a joint report as to the possibility of reconciling the rival claims on silk.[1]

V.—The Reduction of the 1917 Gun Ammunition Programme, February to April, 1917.

The reduction of programme which became necessary in the beginning of 1917 marks the point at which the Ministry began to treat with the War Office on equal terms in the formulation of programmes. In February, 1917, it became apparent that the supply of shells had outrun the supply of guns to fire them. Trustworthy figures as to the life of guns were very difficult to obtain, but as soon as a position was reached in which the rate of gun-fire was no longer limited by lack of shells, it became clear that wastage of guns through wear alone would be enormous. General Du Cane had drawn attention to this point in September, 1916, and in January, 1917, the War Office made various estimates as to the number of guns that would require replacement if the establishment was kept at its full strength, each gun firing its full ration every day. On investigating the position the Ministry found that the rate at which guns were being repaired would not be sufficient to keep in the field throughout 1917 the establishment of guns required by the Commander-in-Chief.

Important results followed—the provision of facilities for the repair of guns and carriages on a much larger scale and the reduction of the gun ammunition programme in order to release steel, labour, and machining capacity. The Ministry made calculations of the ammunition which could usefully be provided, taking into account the number of gun bodies which it was estimated by the Gun Manufacture Department would be forthcoming and the total number of rounds which these guns could fire before being completely worn out. The figures thus obtained were checked by comparison with the number of rounds per gun per day which had been fired in previous periods, and with the daily ration which the Commander-in-Chief had asked for. When it was discovered that the lives of guns as set out in the War Office letters of January, 1917, were based on full charges, the calculations of the Ministry had to be revised as, of course, the guns in the field frequently fired reduced charges and therefore could be expected to fire a larger number of rounds before they were worn out. The number of rounds to be taken as the life of the gun was henceforward determined by the Ministry.

A table was drawn up (13 February) showing that if the number of rounds provided for by the October programme was fired, the Commander-in-Chief would be relying on guns which had only 15 per

[1] Minute by Dr. Addison, 30 November (A.C. 2).

cent. of their serviceable life remaining. It was therefore obvious that since shell provision was ample it ought to be curtailed with a view to liberating resources of steel, machinery and labour for gun repair.[1]

At the same time, two other factors made a reduction of the shell programme imperative—the necessity of economising tonnage owing to losses caused by enemy submarines, and the pressing need of steel for merchant shipbuilding.

The transport question affected the gun ammunition programme in two ways. In the first place, there was the necessity of economising trans-Atlantic tonnage and reducing to the minimum the amount of steel, forgings, shell, propellant and high explosive brought from the United States and Canada, and in the second place the programme was limited by the amount of cross-channel tonnage available and by the capacity of the French railways. On 15 February the Master-General of the Ordnance stated that the total tonnage available for shipping munitions of all kinds to France would during the next nine or twelve weeks be only 45,000 tons a week, 4,000 tons of which were required for trench warfare stores, small arms ammunition, etc. Again, the limit of the amount of finished gun ammunition which could be handled by the French railways had already been reached.[2]

The shipping shortage both decreased the amount of steel available and increased the demand for it, and this scarcity of steel dominated munitions programmes until the end of the war. It became necessary to ration not only Ministry departments' but Government Departments' supplies of steel. These restrictions limited the amount of steel which could be set apart for gun ammunition, and the practice in formulating the later programmes was that the Ministry stated the total amount of ammunition that the tonnage situation would make it possible to supply, and left it to the War Office to determine, with some assistance from the Ministry, how the total should be allotted between the various natures of shells.

In view of all this it was decided, at a conference between the War Office and the Ministry on 15 February, that the output of filled complete rounds must be limited.[3] Certain figures were decided upon at this meeting, which, however, were modified by the War Office in a letter of 23 February. Another change was suggested by the Shell Manufacture Department and the Department of Requirements and Statistics, in consultation, who proposed (23 February) that the War Office programme should be increased with regard to the 6-in. gun, the 8-in. howitzer and 9·2-in. howitzer, and 12-in. howitzer, for various reasons—viz., to allow for a 50 per cent. increase in the life of 6-in., 8-in. and 9·2-in. howitzers by the use of reduced charges, to avoid too great dependence on overseas supplies, and to keep in existence capacity for the supply of heavy shell which would probably have to be revived.

[1] Letters from War Office to Ministry, 31 January, 13 February and 23 February, 1917 (D.M.R.S. 404 D.). Notes of a conference on gun repair, 15 February (A.C. 71).

[2] D.M.R.S. 440; D.M.R.S. 440 C.; A.C. 71.

[3] A.C. 71.

These various sets of figures are compared with the existing programme in the following table :—

	Existing programme as settled Jan., 1917.	First version of revised War Office programme 15 Feb., 1917.	Second version of revised War Office programme 23 Feb., 1917.	Programme proposed by Shell Manufacture and Requirements and Statistics Departments, 23 Feb. 1917.	Third version of War Office programme 7 May, 1917.
18-pdr.	1,200,000	1,200,000	1,200,000	1,200,000	—
4·5-in.	314,000	314,000	314,000	314,000	—
60-pdr.	127,000	90,000	90,000	90,000	—
6-in. how.	295,000	200,000	225,000	225,000	—
6-in. gun	16,200	16,200	8,000	10,000	—
8-in. how.	86,000	50,000	65,000	65,000	—
9·2-in. how. ..	63,000	30,000	37,500	42,000	40,000
12-in.	4,000	Nil.	Nil.	800	3,500

It will be seen that though the demand for 18-pdr. and 4·5-in. ammunition was unaltered, there was a considerable drop in the demand for 6-in., 8-in., 9·2-in. and 12-in. shell, as compared with the October figures and the shell manufacturing programme was revised accordingly.[1]

The effect of the unrestricted submarine campaign was another cut in the programme. On 27 March the War Office stated that only 5,000 tons of munitions a day could be transported to France, and as this included trench warfare materials, the Ministry reduced its filling programme to a level which would provide 40,000 tons of filled ammunition per week.[2] The effect of this would be that the stocks in England would increase for a time, but if shipping facilities improved they would diminish, until in September only a minimum working stock remained. Shipments of 8-in. and 9·2-in. from the United States of America and Canada were to be deferred until after the end of August in order to provide additional tonnage for shipping grain.[3]

VI.—The Programmes for 1918.

(*a*) MAY, 1917.

By May the prospects of shipping ammunition to France had improved. The Commander-in-Chief anticipated that it could be shipped at the rate of 44,500 tons a week, and the current Ministry

[1] Vol. X, Part III, Chap. III.
[2] D.M.R.S. 440 C.
[3] *Ibid.*

filling programme was, therefore, brought up to that level.[1] At the same time a very large programme for filled ammunition based on the War Office requirement for guns was adopted for 1918 :—

18-pdr.	1,400,000
4·5-in.	342,000
60-pdr.	190,000
6-in. how.	330,000
6 in. gun	20,000
8-in. how.	68,000
9·2-in. how.	68,000
12-in. how.	2,500

A correspondingly large manufacturing programme was sanctioned (24 May)[2] which will be found elsewhere,[3] and it was proposed that large orders should be placed in Canada and the United States of America in order to economise home steel for shipbuilding. The programme would provide a total quantity of nearly 66,000 tons of filled ammunition per week, as shown in the following table :—

TONNAGE OF WEEKLY FILLING PROGRAMME.

25 May, 1907.

	Total		For France		For Other Theatres		For Allies	
	Rounds.	Tonnage.	Rounds.	Tonnage.	Rounds.	Tonnage.	Rounds.	Tonnage.
18-pdr.	1,400,000	17,500	1,200,000	15,000	200,000	2,500	—	—
4·5-in.	342,000	7,270	256,000	5,440	40,000	850	46,000	980
60-pdr.	190,000	6,555	180,000	6,210	10,000	345	—	—
6-in. how.	330,000	16,410	319,000	15,860	11,000	550	—	—
6-in. gun	20,000	1,060	19,400	1,030	600	30	—	—
8-in. how.	68,000	6,530	68,000	6,530	—	—	—	—
9·2-in. how.	68,000	9,350	68,000	9,350	—	—	—	—
12-in. how	2,500	890	2,500	890	—	—	—	—
	—	65,565	—	60,310	—	4,275	—	980

The Shipping Controller anticipated (9 June, 1917), that this quantity could be shipped later on, though as the shipments to France then averaged only 50,000 tons a week, considerable additional storage would have to be provided in Great Britain. At this moment the financial position in the United States had a seriously restrictive effect. The Treasury had to withhold its sanction from continuation orders for 6-in. shell, while in France 6-in. ammunition was being fired at the rate of 382,000 a week. Stocks in France were running down fast and Sir Glynn West pointed out (22 June) that if no orders were placed in America the demands of the War Office could not possibly be met.

The Cabinet was, therefore, asked (12 July) to decide several important points :—

(*a*) Whether financial considerations would enable orders to the value of 33,000,000 dollars a month to be placed in Canada.

[1] D.M.R.S. 540.
[2] War Office letter, 4 July (D.M.R.S. 535).
[3] See Vol. X, Part III, Chap. III.

(b) Whether 100,000 6-in. shell a week might be ordered in the United States.

(c) Whether the tonnage demands of this programme, approximately 300,000 tons a month from North America and 1,400,000 tons a month from all sources, could be sanctioned.

The Cabinet decided in the affirmative (before 18 July)[1] and provision was made for storing large stocks of filled shell.[2]

(b) SEPTEMBER, 1917.

This very large programme was not in operation long. On 29 July the War Office put forward a programme for supply from 15 July, 1917, to 15 November, 1918,[3] the chief feature of which was a considerable decline in the demand for 18-pdr. ammunition owing to the shortage of guns and another large increase in the demand for 6-in. howitzer ammunition, which, the War Office reported, grew more popular every day.

Taking into account the existing stocks,[4] and with some help from Canada and the United States, the Ministry expected to be able to meet this programme except for 6-in. howitzer ammunition.[5] A return to American production would have to be made for 6-in. howitzer shell only and considerable orders both for shell and components would have to be placed in Canada.[6] . The programme allowed for ammunition to be sent to those Allies to whom guns of British pattern had been allocated, and involved a weekly production of filled shell averaging 51,000 tons over the whole year. It was designed to provide the Army with about 66,000 tons of ammunition weekly during the coming campaign—April to November, 1918—and 17,000 tons weekly during the winter months (November, 1917, to April, 1918). This would allow of a considerable increase over the actual expenditure during the battle period of 1917, which had averaged 43,300 tons a day over a period of 37 weeks, and more than two and a half times the weight of ammunition used in the Somme battles, when the weekly expenditure had averaged 25,394 tons.[7] Practically the whole of the increase in the weight of the programme was due to the increased provision of

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[1] Meeting in Minister's room, 10 July, 1917. Memorandum by Minister of Munitions, 12 July, 1917. D.M.R.S. 555.

[2] The stocks of filled shell were to rise from 254,000 tons at the beginning of November to 1,038,500 tons by 1 April, 1918.

[3] For detailed figures, *see* Appendix.

[4] *Review of Munitions Programme*, October, 1917; HIST. REC./R/1000/66.

[5] Meeting on Filling Programmes (18 July, 1917). The 6-in. howitzer position was aggravated by the fact that the War Office had asked for 300,000 rounds in August in excess of the regular supply.

[6] The new programme would involve a weekly expenditure of \$39,000,000 in the U.S.A. and \$28,000,000 in Canada, as compared with an expenditure of \$61,000,000 in U.S.A. and \$45,000,000 in Canada during the first half of 1917.

[7] HIST. REC./R/1300/93; *Review of Munitions Programmes*, October, 1917, p. 12.

ammunition for the 60-pdr. and 6-in. guns, and the 6-in., 8-in. and 9·2-in. howitzers. The reason that this increased output could be secured without involving a further large call on tonnage and on manufacturing capacity was that munitions output only reached high-water mark in the Spring of 1917, and that during the year heavy artillery had been able to live on the current income of ammunition. If the factories were kept working at full output during the Winter of 1917 they would produce a very large stock to add to the next year's production for the 1918 campaign. This was the last big lift that could be given to the ammunition supply. The adoption of this programme involved the storage of filled ammunition in Great Britain on an unprecedented scale. The amount stored had not hitherto exceeded 200,000 tons, but as the Army could not store in France in the Winter on a sufficient scale, arrangements were made for storing up to a maximum of 550,000 tons in readiness for the 1918 campaign.[1] These reserves would be expended during the Summer, but it was anticipated that sufficient stocks would remain to carry forward for another campaign.

(c) DECEMBER, 1917.

The decision of the Milner Committee of the War Cabinet (December, 1917), that the tonnage allotted for the importation of munitions must be reduced to 11,000,000 tons a year, meant a reduction in the importation of iron ore and a decline in the output of steel upon which the munitions budget and the existing gun ammunition programme were based. The steel output would fall from 10,000,000 to 8,500,000 tons, and as a result the programme for gun ammunition had to be reduced by nearly 20 per cent.,[2] while the supply of filled ammunition for the Summer campaign would fall from 66,000 tons to 53,000 tons a week.

The programme drawn up by the Ministry on this basis proposed the elimination of supplies to Russia and the reduction of the allocation to theatres of war other than France by 25 per cent. It was assumed that the number of divisions on the Western front would not be increased, and that the equivalent of the empty stocks then in the country would be set aside for 1919. The reasons for this latter assumption were given thus in a letter to the War Office (17 December, 1917) :—

> "As it is clear that we cannot assume that the war will be over in 1918, it would not be prudent next year to use up entirely the surplus stocks which have been accumulated both in France and Great Britain during a period when tonnage has been more abundant than at present. These surpluses should certainly be preserved for unforeseen contingencies and to allow of a supreme effort when the culminating point of the war is reached. It is therefore suggested that in order to give the Army in 1919 an approximately equal income to that available next year, expenditure as far as circumstances allow should be adjusted to enable

[1] *Review of Munitions Programmes*, October, 1917, p. 17.

[2] Letters to War Office, 17 December, 21 December, 1917 ; and to Shipping Controller, 2 January, 1918, 18 January, 1918, 25 January, 1918. (D.M.R.S. 555.)

our empty stocks at home, which represent roughly some 300,000 tons of completed ammunition, to be carried forward to 1919, while the surplus filled stock is allocated to 1918. This arrangement will give roughly 53,000 tons a week in the summer of 1918 and 57,000 tons a week in the summer of 1919, as against 45,000 in the current year and 67,000 tons a week according to the arrangements at present in hand for 1918, which in addition provide the full ration for other theatres and some 105,000 tons during the year for Russia."[1]

The average weekly requirement of filled ammunition under the new programme, which was adopted on 10 January, 1918,[2] was as follows:—

18-pdr. S.	391,000	
18-pdr. H.E.	252,000	(17,000 chemical and 20,000 smoke shell at first included, later 50,000 chemical and 20,000 smoke shell additional to the programme figures).
4·5-in. H.E.	183,000	
4·5-in. Chemical	26,000	(7,000 smoke shell at first included, later additional to figures given).
60-pdr. S.	37,000	
60-pdr. H.E.	36,250	
6-in. how. H.E.	280,000	
6-in. " Chemical	30,000	
6-in. gun H.E.	6,440	
6-in. " S.	5,860	
8-in. H.E.	50,700	
9·2-in. H.E.	33,700	
12-in. H.E.	2,325	
15-in. H.E.	220	

This represented the production of 41,000 tons of ammunition weekly over the whole year and a filling programme at that level was arranged for.

The Secretary of State for War made a strong protest to the Cabinet (2 January, 1918) against a proposal to cut down the allocation of munitions tonnage to 10,000,000 tons and thus reduce still further the gun ammunition programme for 1918. The programme had already been cut down by 18½ per cent., reducing the amount of ammunition to be supplied during the year by 500,000 tons, and he thought it would be fatal to permit any further restriction.[3] The infantry had been trained for the last two years to rely upon a preponderance of artillery fire, and as the Germans would be able to transfer a large amount of artillery from the Eastern to the Western front, it would be difficult even on the existing programme to give the infantry all the artillery support they required. With the prospect of very severe defensive fighting during the coming months it would be disastrous to run short

[1] D.M.R.S. 555.

[2] *Ibid.*

[3] Minutes of Co-ordinating Committee, 11 February, 1918. (HIST. REC. R/1000/61.)

of field gun ammunition, so that, if the proposed cut were made, it would have to be in the heavy shells employed largely for counter-battery work. The value of these heavy shells was proved by a memorandum by Ludendorff (dated 4 October, 1917), recently captured, which showed that 60 per cent. of the damage done to German field guns and 66 per cent. of the damage to their heavy artillery was due to British counter-battery work.

Though the Cabinet decided that the tonnage budget must be reduced by 1,000,000 tons to 9,000,000 tons, the programme for gun ammunition was maintained, the reduction being confined to other services, by cutting down the allocation of steel for the Admiralty, the War Office, railways, trench warfare, etc.[1]

Mr. Churchill had hoped to arrange a supplementary programme of gun ammunition based upon the importation of additional steel from America, but this was found to be impossible, as no further allocation of credits in America could be obtained and additional tonnage was not available.[2] Therefore, the programme providing for a maximum of 53,000 tons of filled ammunition a week during the battle period of 1918 was maintained. Mr. Churchill pointed out, however (19 March, 1918),[3] that this level of supply could only be kept up by drawing very largely on reserves and that the reserves at the end of the year would be much smaller than at the beginning. So far expenditure had not reached the estimates, and any saving could be carried forward to strengthen the position in 1919, since it was impossible to hope that more tonnage for steel and iron ore would be available than in 1918.

(*d*) MAY, 1918.

The next revision of programme, therefore, left the total tonnage of filled ammunition to be provided unaltered. The chief features of this revision, which was based on the experience of the recent open fighting, were a marked increase in the demand for light shell, for smoke and chemical shell, and for 6-in gun shell, a diminution in the demand for heavy howitzer shell, and a large demand for heavy ammunition for the Allies—at the rate of 21,400 rounds of 6-in. howitzer ammunition, 17,000 rounds of 8-in. howitzer ammunition, and 1,900 rounds of 9·2-in. howitzer ammunition weekly.[4]

The Army Council suggested (25 May) that as soon as the home stocks of any nature of ammunition equalled eight weeks' requirements,

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[1] HIST. REC./R/1000/63.

[2] Ministry to War Office, 14 January, 1918. (D.M.R.S. 555.)

[3] In March, priority both in loading and shipping space was given to cereals. Ministry of Shipping to Ministry of Munitions, 18 January, 1916, 25 January, 1918 (C.R.V./Gen./0461). Conference at G.H.Q., France; Letter to War Office, 14 April, 1918 (D.M.R.S. 555).

[4] War Office letters, 18 April, 3 May, 1918 (D.M.R.S. 555); 121/Stores/8683; *Review of Munitions Programmes*, June, 1918; HIST. REC./R/1000/61 (14 May, 1918). For details of this programme, *see* Appendix.

production should be reduced to the equivalent of the quantity shipped overseas weekly. The Ministry opposed this suggestion. While the filling programme was capable of variation on short notice, empty shell production was not, since changes once made could not be altered without difficulty. The existing manufacturing programme could not be altered unless the General Staff considered that the intake of ammunition from September to the end of the year could safely be modified and that a sudden increase of output would not be required early in 1919.[1]

In spite of the heavy losses of ammunition during March and April,[2] the expenditure of gun ammunition during the first five months of the 1918 campaign was considerably below estimates, and over the whole campaign it averaged only 41,800 tons weekly—slightly less than the expenditure in the 1917 battles.[3] In the late Summer, however, when the Allied advance began and there was a long period of open fighting, the rate of expenditure rose rapidly. In the last week of September, when it reached a climax, 83,000 tons of gun ammunition were fired, 2,500,000 rounds being used in three days.[4]

VII.—The Programme for 1919.

This experience of the high level of expenditure in the 1918 campaign led G.H.Q. to put forward in September a very large programme for 1919 (involving a weekly output of 55,011 tons of filled ammunition exclusive of supplies to the United States, and further supplies to the Allies)[5] the details of which will be found elsewhere.[6]

Mr. Churchill pointed out (26 September, 1918), that there was no foundation for the view that the conditions of semi-open warfare which had now supervened in France and the abandonment of the prolonged artillery bombardment previous to assaults would afford any relief in shell consumption. On the contrary, the heaviest firings yet recorded had taken place in France during a period of open warfare. For fifteen successive days the expenditure had exceeded 10,000 tons a day.

> " These very wide battles, fought on the fronts of two or three British armies simultaneously, in which almost all the guns in France are employed, use more and not less ammunition than was

[1] 26 June, D.M.R.S. 555.

[2] On 7 April the stock of filled ammunition in France was 323,323 tons, as against an estimate of 505,940 tons (HIST. REC./R/1000/63, March, 1918), and at the end of the month the stock had declined to 287,000 tons as against an estimate of 477,800 tons (HIST. REC./R/1000/63, April, 1918). When the war ended a stock of 555,390 tons of filled ammunition, representing 13½ weeks' expenditure, remained.

[3] In the 1917 battles an average of 1,586,000 rounds (42,300 tons) per week were fired as compared with 1,611,000 rounds (41,800 tons) in 1918 battles, a larger proportion of light and medium and a smaller proportion of heavy ammunition being used in 1918.

[4] HIST. REC./R/1300/93.

[5] D.M.R.S. 595; Minutes of Co-ordinating Committee (28 September 1918).

[6] Appendix.

required for the intense local fighting of Messines, Passchaendale, etc. On the other hand, this great consumption of ammunition is being attended by remarkable results. A recent order of General Ludendorff's, which has been captured, states that in a single month more than 13 per cent. of the German artillery in the West has been completely destroyed by counter-battery fire. As this method is comparatively little used by the French, the main credit of this astonishing achievement falls to the British artillery. . . . . It would be disastrous if, for any reason, we were compelled to stint our gunners in ammunition at the very time when the result of all the immense efforts which have been made to increase the power and perfect the combination of our Artillery and Air Services is coming to hand. Rather than do that we ought to be ready to make very great sacrifices indeed in every direction.

"Pursuant no doubt upon these results, a demand for ammunition for 1919 has been made by G.H.Q., which is considerably in excess of the amount for which I was previously providing. This year I drew considerably on the stocks of empty shell and shell steel which had accumulated, and I propose still further to do so. I propose also to budget for an inroad of at least 25 per cent. upon the reserves of filled shell which will be left at the end of the fighting season. After making allowance for all these serious steps, I cannot meet even the original and non-augmented shell programme of the War Office with a less provision than 1,200,000 tons of shell steel for the land service from home sources."

In view of the coal shortage, however, a cut in munitions programmes had to be contemplated and Mr. Churchill stated (1 October) that on account of tonnage and coal restrictions the Ministry could not undertake to provide more than 41,000 tons of filled ammunition weekly, which would allow 50,000 tons a week during the Summer of 1919.[1] Even this programme would involve the import for munitions purposes of 11,000,000 tons during 1919. If filling proceeded at the programme rate of 41,000 tons and expenditure fell to 18,400 tons a week from 1 December to 1 March, a total stock of 700,000 tons of filled ammunition would be left by the Spring of 1919. He urged the increasing importance owing to the stringency in the labour and materials positions of avoiding alterations in programme when once fixed.[2] It was on this basis that the 1919 programme was being worked out at the date of the Armistice.

VIII.—Demands for Long Range Shell.

The increasing demand for long range shell was a special feature of the later gun ammunition programmes. The marks of shell in use during the first year of the war had two calibre radius heads, but from the beginning of 1916 onwards the War Office laid great stress on the necessity of

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[1] D.M.R.S. 595; Minutes of Co-ordinating Committee. (3, 6, 7 and 28 September, 1918.)
[2] D.M.R.S. 595.

lengthening range by improvements to guns, increasing the length of shell, and the provision of longer burning time fuses.[1] The Commander-in-Chief stated that a supply of 6-in. and 9·2-in. shrapnel with 4-calibre radius heads would be of great value at the longest possible range against large formations of men, collections of huts, etc. The Ministry reported (26 September, 1916) that 4-calibre radius head (c.r.h.) shell would be in supply by November for the following guns, the 4·7-in., 6-in., 9·2-in. and 12-in. Part of the supply of 4·7-in. shrapnel and of 9·2-in. H.E. was already of the 4 c.r.h. type, but no steps had been taken to supply 4 c.r.h. shell for the 60-pdr. gun.[2]

The supply of 4 c.r.h. ammunition for the new high velocity howitzers—the 8-in., 9·2-in. and 12-in.—was under consideration in December, 1916, as it was anticipated that the 4 c.r.h. shells would give a range of 700 yds. more than the 2 c.r.h. shells.[3] The change over would involve a loss of production spread over about three months, but the Army Council agreed (24 January, 1917) that the longer range type must be provided and recommended that 2 c.r.h. shells should be allowed to die out for these howitzers.[4]

In the meantime the Commander-in-Chief had been asking for shell with 8-calibre radius heads for all the guns in the field.[5] On 24 June, 1916, he had written on this subject to the War Office, who forwarded his letter to the Ministry on 2 July, and on 1 January, 1917, he wrote personally to Dr. Addison urging the importance of providing shell of the 8 c.r.h. type for the 60-pdr. gun, which was to play an important part in the operations planned for the Summer of 1917. Special importance was attached to obtaining as long a range as possible with the 12-in. gun, and the War Office asked for a supply of 12-in. shells with 8 c.r.h. nose caps (18 September, 1916).[6] On 19 December the Ordnance Committee were asked to get out a design for 8 c.r.h. shell for the 60-pdr. gun, and the design having been approved Dr. Addison wrote (8 January, 1917) proposing to change over the whole of the shrapnel production and part of the H.E. production to the 8 c.r.h. type, but warning the Commander-in-Chief that very little of the long-range shell could be expected in France before the third quarter of 1917.[7]

The older type of shell was gradually given up, and on 17 May, 1918, it was decided that the manufacture of 2 c.r.h. 8-in. and 9·2-in.

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[1] 121/Stores/4850. C.R.4428.
[2] D.M.R.S. 404 B.
[3] *Ibid.*
[4] *Ibid.*
[5] Letter from Sir D. Haig to Dr. Addison, 2 January, 1917, quoting letter to War Office 24 June, 1916. D.M.R.S. 404 O.
[6] D.M.R.S. 390. There was great difficulty in obtaining a reasonable degree of accuracy with these shells. This delayed supply, and in March, 1917, some naval shells with false caps were sent out as a stopgap. Letter from Dr. Addison to Sir D. Haig, 13 March, 1917. (HIST. REC./R/1300/125.)
[7] D.M.R.S. 404 O.

shell should be discontinued as the 4 c.r.h. shell gave an increased range of 400 yds. The existing stocks of 2 c.r.h. shell would be sufficient for the remaining lives of the old marks of these howitzers.[1]

On 24 June, 1918, the War Office informed the Ministry that G.H.Q., France, was convinced of the paramount importance of increasing the range of British guns and howitzers. British shells did not range as far and were not as accurate as those used by the enemy, who had obtained a great increase in range by the use of shell fitted with false caps and in some cases stream-line bases. Up to the present only H.E. shell with percussion fuses could be used with false caps, but the advent of mechanical time fuses would allow the use of false caps with shrapnel shell.[2] The efforts of the Supply Departments to meet these demands are dealt with elsewhere.[3]

IX.—Incendiary, Smoke, and Chemical Shell Programmes.

(*a*) SMOKE SHELL.

The demand for projectiles which would produce smoke clouds to screen the movement of troops arose in the Summer of 1915, it being "obviously a condition that the smoke produced should be of a comparatively harmless nature."[4] The efforts of the Trench Warfare Supply Department to supply bombs filled with red phosphorus, which was later to be changed by request of the War Office to white phosphorus, are dealt with elsewhere.[5] In the Summer of 1916 G.H.Q. asked for the provision of smoke shell for artillery to form a smoke barrage, and the filling of steel 4·5-in. container shell with white phosphorus began in September, and of 18-pdr. steel shell with a tin container a few months later.[6] Later on, when supplies of container shell were not forthcoming, a double diaphragm 4·5-in. shell was used for phosphorus filling.[7]

In the summer of 1917 demands from France for smoke shells increased rapidly, and from November onwards experiments with shells filled with a mixture of red and white phosphorus were carried out. As the heavy burster required to open the steel types of smoke shell dissipated the smoke effect, cast-iron shell were recommended as preferable to steel shell for phosphorus filling (15 August, 1917), and at the end of the war the bulk of the smoke shell supplied was of this type.

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[1] Minutes of Co-ordinating Committee (17 May, 1918).
[2] 57/3/5472 in D.M.R.S. 440 Z.
[3] Vol. X, Part III, Chap. III.
[4] History of Chemical Advisory Committee, by Capt. J. D. Pratt, Vol. II, p. 56 (HIST. REC./H/1650/9).
[5] For further details relating to smoke shell, see Vol. XI, Part II, Chap. VII.
[6] D.M.R.S. 296 H. By March 20,000 had been issued (HIST.REC./R/1300/125).
[7] HIST. REC./H/1650/9, II, p. 272.

(*b*) INCENDIARY SHELL.

A letter to the War Office from G.H.Q. France, 25 October, 1915, stated that incendiary shell would be very useful for the destruction of buildings in the enemy's front line that were used as observation posts. The destruction of such buildings by the means of H.E. shell entailed a considerable expenditure of ammunition, and they would be more thoroughly destroyed by fire. Since such targets were more easily hit by guns than by howitzers, a satisfactory incendiary shell for the 18-pdr. gun would be preferable to a shell for the 4·5-in. howitzer, but an efficient incendiary shell for the 4·5-in. would be in every way preferable to an inefficient shell for the 18-pdr. gun.[1] Some months later (27 March, 1916) G.H.Q. took up the matter again and wrote to ask if any progress had been made in the provision of incendiary shell. It was suggested that shell rejected for high explosive filling should be filled for incendiary purposes with a bursting charge of black powder, provided that the output of H.E. shells was not thereby delayed.[2]

The Ministry of Munitions had already put a similar proposal before the War Office. On 10 March the Ministry informed the Army Council that the question of filling with powder all H.E. shell rejected as unsuitable for filling with high explosive was being considered, that trials had been carried out with shells so filled, and that it had been found that the burst was good. It was thought that the burning powder scattered about would give a good incendiary effect, and that the smoke from the burst of the shell would facilitate ranging, and observation of fire from aircraft.

The Ministry enquired whether the Army Council was prepared to accept powder-filled shells of this kind.[3] The War Office replied (16 March) asking for particulars of the fragmentation trials of all the natures of H.E. shell proposed to be filled in this way,[4] and were informed (20 March) that it was proposed to issue powder-filled shells for 6-in., 60-pdr. and 4·7-in. guns, and 4·5-in. howitzers, and that the trials indicated that powder-filled shells of the calibres mentioned would give good results.[5] The War Office again asked for particulars of the trials (30 March),[6] but the Minister of Munitions stated (3 April) that this request did not appear to him to conform with the definition of the respective responsibilities of the War Office and the Ministry as laid down in the War Office letter of 25 November, 1915, which gave the responsibility for the design and testing of ammunition to the Ministry.[7] Mr. Lloyd George therefore reiterated that, in the opinion of the responsible advisers of the Ministry, the trials already carried out showed that the shells were likely to prove satisfactory. It was not considered that further trials were necessary, and in view of the frequent complaints from the Army as to the difficulty of observing the bursts of H.E. shell from the air, Mr. Lloyd George was anxious to make arrangements for the supply of these shells at once. If a

[1] D.G.M.D./S/322. [2] *Ibid.* [3] *Ibid.*
[4] 75/12/9346. [5] D.G.M.D./S/322. [6] 75/12/9346. [7] D.M.R.S. 356.

practical trial in France was considered desirable, arrangements could be made at short notice to send over some ammunition for the purpose. On 4 April the Army Council enquired how the issue of incendiary shell for the 18-pdr. gun and the 4·5-in. howitzer would affect the supply of fuses for high explosive rounds,[1] but a few days later (12 April) the Army Council stated that it would be glad to accept powder-filled shells, up to 5 per cent. of the output, for the 6-in., 60-pdr. and 4·7-in. guns, and for the 4·5-in. howitzer.[2] On this basis the weekly War Office requirements for powder-filled shell were as follows[3] :—

	4·5-in.	4·7-in.	60-pdr.	6-in.
May	4,000 per week	500	1,000	750
June	5,000 ,,	500	2,000	1,000
July	6,500 ,,	500	2,500	2,000
August	8,000 ,,	500	3,000	3,000
September	9,000 ,,	500	4,000	4,000

The fuses approved for this shell were—

No. 17,
No. 44 (filled powder and shutter removed),
No. 100,

and it was thought probable that a sufficient number of No. 100 fuses would be available for this requirement for powder-filled shell without interfering with the completion of H.E. rounds, since the supply of filled No. 100 fuses was far ahead of the capacity for assembling fuses and gaines. The Chief Inspector, Woolwich, was asked to mark rejected shell as either finally rejected or as suitable for powder-filling, and this supply of powder-filled shell was regarded as being in addition to, and not in substitution for, any part of the shell programme. The issue of powder-filled shell began about 28 April, 1916.

In order to make the supply of empty shell for powder filling as large as possible the Design Department, on 5 June, decided that all 6-in. H.E. shell, whether for guns, howitzers, or both, should be accepted for powder filling, whatever the mark.[4]

These H.E. shells filled with powder were not very satisfactory in use. A number of prematures were reported from France, and on 18 July the Design Department informed the Director of Artillery that it had been decided not to issue any more of this type of projectile.[5] Shell already prepared, before the decision to cease buying these shell had been communicated to contractors, would be accepted.[6]

[1] 75/12/8721.
[2] 75/12/9346 in D.M.R.S. 356.
[3] 75/12/8721.
[4] D.M.R.S. 356.
[5] D.G.I.M./S/161, D.M.R.S. 356.
[6] Minutes of National Projectile Factories Committee, 22 September, 1916. (M/Gen./124.)

Before the supply of powder-filled shells began the Commander-in-Chief had asked (20 April, 1916) for a shell giving the maximum possible incendiary effect, stating that something more than powder-filled shell would be necessary. It was probable that incendiary shell would be required during the Summer for long range guns, especially for the 6-in. Mark VII and the 9·2-in. guns, and stress was laid on the fact that unless the shells were received during the dry Summer months they would be useless.[1] The Ministry was unable to make any definite promise as to supply (2 May). Trials to obtain an effective design for incendiary shell for the 4·5-in. howitzer were going on, but they had not so far been successful.[2]

(c) THERMIT-FILLED SHELL.

In his letter of 16 May, 1916, in addition to incendiary shell for the 4·5-in. howitzer, the 6-in. Mark VII gun, and the 9·2-in. gun, the Commander-in-Chief asked for a shell filled with "Thermit" or some similar substance for 18-pdr. field guns which would scatter the contents and so be available against personnel as well as for incendiary purposes.[3]

In reply the Ministry reported (2 June) that experiments had been carried out with thermit shells which gave a good incendiary effect, and approval had been given for the manufacture of these shells for the 18-pdr. gun, the 4·5-in. howitzer, and the 6-in. gun. The shell used was the ordinary shrapnel shell, and as no new metal components were required it was hoped that the supply would not be long delayed.[4] The 4·5-in. howitzer had been included, as experiments showed that the best effect was obtained with these shells when used with a steep angle of descent.[5]

On 13 June and 15 June the Commander-in-Chief telegraphed asking that as many 18-pdr. and 4·5-in. thermit-filled shell as possible should be sent to Rouen,[6] but the design for 18-pdr. incendiary shell had not been finally approved, the provisional approval having been revoked owing to failures in the trials. No 18-pdr. incendiary shell were therefore being made,[7] but the Ministry reported on 20 June that it might be possible to send out 2,000 4·5-in. shell in the following week. The Commander-in-Chief telegraphed again on 21 June urging that provision of these shells should be pressed forward, but the next report was disappointing, that only 1,000 4·5-in. thermit shells instead of the 2,000 mentioned were on the eve of delivery.

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[1] 75/12/9363 in D.M.R.S. 356.

[2] D.M.R.S. 356.

[3] *Ibid.*

[4] Provisional approvals were given on 27 May. The central tube and tin cup were filled with ophorite, the bullets being replaced by thermit. (Printed) *Weekly Report*, No. 43, XII (27 May, 1916).

[5] D.M.R.S. 296.

[6] 75/12/9362 in D.M.R.S. 356.

[7] D.G.M.D./S/604. The suspension of approval was removed on 22 July.

The 4·5-in. thermit ammunition was regarded at first as very satisfactory,[1] and on 5 July the Commander-in-Chief telegraphed asking what further supply could be expected in the near future, while on the following day G.H.Q. telegraphed that further supplies of thermit shells were urgently required, and that their despatch should be hastened if possible.[2]

Instructions for the use of the 6-in. incendiary gun shell (11 July, 1916) stated that the shell might be expected to give its best results when burst in the air low down. It burst with a good smoke effect, and had been found to set fire to green grass, which, when burning, caused a considerable smoke cloud. The fuse used was No. 82.[3]

The fuse recommended at first for the 4·5-in. howitzer chemical double diaphragm shell was the No. 100, but when the shell was fired with a steep angle of descent it was found that this fuse did not act quickly enough, with the result that as the shell had time to enter the ground the chemical effect was lost. It was reported, therefore (8 May), that the No. 44 fuse would probably have to be used for all howitzer chemical shell, the head of the shell being filled with H.E. or powder.

On 18 September, 1916, the War Office stated that no further supplies of 6-in. and 9·2-in. thermit-filled shell where required, as the provision of these shells was not justified by experience with thermit to date.

(*d*) Chemical Shell.

As a result of the German gas attack at Ypres (22 April, 1915) experiments were undertaken at South Kensington which resulted in the production of a powerful lachrymatory liquid, known from its place of origin as S.K., which was at first supplied in grenades made by the Trench Warfare Supply Department.[4] At the same time experiments were being made in pursuit of a design of shell which would enable S.K. to be used by artillery. In the Summer of 1915 a small number of 4·5-in. shell, with containers to hold chemical liquid, were manufactured and sent to the Grenade Section of the Trench Warfare Supply Department for filling, the first S.K. artillery shell being fired at proof in July. G.H.Q. repeatedly asked for some means of using asphyxiating gas in addition to the hand grenades already supplied as a stopgap measure,[5] and at a conference at Boulogne (19 June) it was decided that there must be a great development in chemical warfare.

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[1] Capt. Pratt states that in spite of a large amount of experimental work, it was not found possible to produce a really effective thermit shell. *Op. cit.*, p. 300.

[2] For copies of this series of telegrams, see D.M.R.S. 356.

[3] D.G.M.D./T/168.

[4] For further details relating to chemical shell, see Vol. XI, Part II, Chap. I.

[5] 23 May, 16 June, 1915.

A definite demand for 10,000 4·5-in. cast-iron lachrymatory shell was made in October, 1915. Manufacture was started at once; the first delivery of empty shell reached the filling station in February, 1916,[1] and the whole of the 10,000 rounds reached France by the end of April.

In a series of letters (29 January, 26 February, 7 April, 8 April, 19 April, 21 April, 26 April, 1916) Sir Douglas Haig asked for chemical shell for artillery filled with S.K. or some other gas. Shell for the 4·7-in. and 60-pdr. guns and the 4·5-in. howitzer were first asked for, demands for shell for the 6-in., 8-in., 9·2-in. and 12-in. howitzers and the 6-in. Mark VII gun being added later. The supply of shells to hold chemicals was regarded by the War Office as a matter of special urgency, and it was desired that 10 per cent. of the ammunition supplied weekly should be chemical shell.

In addition to S.K. three other substances were proposed for use in artillery shell in the Spring of 1916:—

(*a*) Jellite—a mixture of hydrocyanic acid and chloroform.
(*b*) C.B.R.—a mixture of phosgene and arsenious chloride.
(*c*) P.S.—chloropicric.

On humanitarian grounds the Army Council would not definitely sanction the use of these lethal shell until the enemy had first used them at Verdun.

(*e*) Sir Douglas Haig's Classification of Miscellaneous Shell.

A very important letter from G.H.Q., dated 16 May, 1916, dealt with the whole question of the demand of the Army for what may be termed miscellaneous shell and bombs, laying down lines of classification which became permanent. The following is an extract from Sir Douglas Haig's letter[2]:—

> "Hitherto, in formulating requirements, I have recommended the provision of bombs and shells filled with certain named substances. In future, as the actual substance provided must depend on manufacturing possibilities, and on the results of the experiments and scientific research which is carried on at home, I propose to confine myself to stating what effect I wish produced by the projectiles of the various natures of mortars, guns, and howitzers, and to leave the choice of the substance for producing this effect to be made at home. It is essential, however, that delivery shall be arranged on the principle that a serviceable article received in time is of value, whereas a better one received too late is useless.

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[1] D.M.R.S. 296. [2] *Ordnance Board Minutes* 816.

"In accordance with the amended system proposed in the preceding paragraph my requirements will be classified in future under three main headings, namely :—

"(*a*) Smoke,
"(*b*) Gas (lachrymatory, including S.K. and lethal),
"(*c*) Incendiary (other than powder-filled shells)."

After giving an estimate of his requirements for smoke and lachrymatory bombs for the 4-in. Stokes mortar, and stating that a sufficient supply of phosphorus for producing smoke in H.E. shells of 4·7-in., 60-pdr. and 6-in. guns for observation purposes must be arranged for, Sir Douglas Haig went on to consider the types of artillery shell which should be filled with chemicals—*i.e.*, gas or incendiary shell. For artillery the gas should be preferably lethal, but failing a sufficient supply of that, both lethal and lachrymatory ; if no lethal could be provided, then lachrymatory only.

The chief uses of chemical shell were summarised as follows :—

Gas Shell—
(1) for counter-battery work,
(2) for barrages,
(3) for use against villages and woods, combined with H.E.

Incendiary Shell—
(1) for use against woods,
(2) for use against villages.

He recommended that shell for these guns and howitzers should be provided in the following quantities :—

	To be provided by 15 June.	*Rate per week thereafter.*
(*a*) *Gas Shell.*		
4·5-in. how.	20,000	5,000
4·7-in. gun	4,000	1,000
60-pdr. gun	16,000	4,000
(*b*) *Incendiary Shell.*		
4·5-in. how.	20,000	5,000
6-in. Mark VII gun	5,000	1,000
9·2-in. gun	1,000	100

The number of 4·5-in. shells shown in (*a*) and (*b*) was based on the assumption that both gas and incendiary shells would be forthcoming. If only one of these natures of shell were available, the numbers shown should be doubled.

The Ministry, however, was unable to promise the reserve of gas and incendiary shell asked for by 15 June. Ten thousand lachrymatory cast-iron shell would be available during June, and a considerable number of lachrymatory steel shell of various types also. It was expected that shell filled with lethal gases would become available in July.[1]

[1] D.M.R.S. 296.

The Ministry at the same time noted the alteration in the proportion of the requirements for chemical shell for the 4·5-in. howitzer and the 60-pdr. and 4·7-in. guns. The requirement for the 4·5-in. howitzer—50 per cent. of the whole—was smaller than in previous statements of requirements, which was advantageous since experiments had proved that a better chemical effect was obtained with gun ammunition than with howitzer, owing to the tendency of the latter ammunition to bury itself. Difficulty had also been experienced in getting a sufficiently instantaneous fuse, and for the present it would be necessary to use for the howitzer fuse No. 44, the supply of which was a restricted one.

(*f*) LETHAL AND LACHRYMATORY SHELL.

As has been seen, on 16 May, 1916, the Commander-in-Chief definitely expressed his preference for lethal shell for artillery work,[1] and on 2 June the Ministry informed the Army Council that it was hoped that shell filled with lethal gases would become available in July,[2] but at the same time pointed out that it was as yet uncertain what effect could be produced by shells filled with phosgene or jellite. The effect of detonation on these volatile substances had not yet definitely been ascertained, nor was it known what degree of concentration was required to produce lethal effect. There was reason to believe that it would be necessary to concentrate a very large number of projectiles in a small space in order to produce any considerable result. Extensive experiments would be carried out as soon as shell were available, and the Minister hoped to be in a position to give more definite advice by the time lethal shells became available for supply to the armies in the field.[3]

The Ministry understood that the requirements for lethal shell as stated on 16 May were distinct from the demand for shells filled with jellite, as the Ministry had so far only been authorised by the War Committee to fill shell with jellite for storage purposes. The jellite that would shortly be available would be filled into 4·5-in. shell and stored.[4]

In the same letter (2 June) the Ministry pointed out that practically all the shell set aside for chemical filling would have to be deducted from the number available for H.E. filling, and asked for a confirmation of the statement in letters of 5 February and 13 March to the effect that ordinary H.E. and shrapnel output might be sacrificed if necessary to the extent of 10 per cent.[5] This confirmation was forthcoming

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[1] D.M.R.S. 356. [2] D.M.R.S. 296. [3] 2 June, D.M.R.S. 296. [4] *Ibid.* [5] D.M.R.S. 356.

with regard to H.E. shell, and the following provisional statement of the weekly requirements for chemical, incendiary, and powder-filled shells was put forward on 22 June[1]:—

	July.*	August.	September and onwards.
Chemical Shell,† 4·5-in.	20,500	12,500	12,500
,, ,, 4·7-in.	4,100	2,500	2,500
,, ,, 60-pdr.	16,400	10,000	10,000
Incendiary Shell,‡ 4·5-in...	13,000	5,000	5,000
,, ,, 6-in. gun	3,000	1,000	1,000
Powder-filled Shell, 6-in., 60-pdr., 4·7in., 4·5-in.	Up to 5 per cent. of total output of ammunition.		

* The weekly rates are higher than in the later months in order to cover arrears. No figures are given for June but any output secured during this month should be written off against the amount demanded in July.

† Of the above, 7,500 4·5-in., 1,500 4·7-in., and 6,000 60-pdr. per week are required for jellite, but shells should not be allocated to this purpose until requirements for other natures of chemical shell have been met.

‡ Additional requirements for 9·2-in. and 18-pdr. incendiary shell will probably be subsequently included.

These requirements were additional to the current demand for H.E. and shrapnel shell, but in case of necessity the supply of H.E. might be reduced by 10 per cent. in order to provide the chemical shell.[2]

On 31 December, as all the 4·7-in. guns in France were being replaced by 60-pdrs. at an early date, instructions were given that the 30,000 lethal shell per week should be supplied in future for the 4·5-in. howitzers and the 60-pdr. only, in the ratio of 8 to 5, and that the 4,000 4·7-in. shell which were in store should be emptied and the metal in them recovered and utilized. Later, on 22 March, 1917, a method of conversion of 4·7-in. chemical and H.E. into 4·5-in. chemical and H.E. was approved.

In January, 1917, there were urgent requests from G.H.Q. for additional supplies of 4·5-in. and 60-pdr. chemical shell, the latter being in special demand, and on 10 February the War Office gave instructions that in the event of requirements conflicting, preference was to be given to the filling of 60-pdr. chemical shell.

The new requirements, as given by the Army Council on 14 February were as follows[3]:—

	Lethal.	*Lachrymatory.*
4·5-in.	19,000 per week. ..	3,000 per week.
60-pdr.	11,000 ,, ..	2,000 ,,

[1] D.D.G. (A) 17138. [2] *Ibid.*
[3] 121/Stores/6633 in D.M.R.S. 296 A.

A little later (27 February), the Army Council stated that they were prepared to eliminate the lachrymatory S.K. filling and to accept 12½ per cent. of the total supply of 4·5-in. and 60-pdr. ammunition as lethal shell. Of this proportion 50 per cent. should be filled with P.S. (chloropicric) which had lachrymatory as well as lethal properties.[1] The requirements after 30 March would be as follows :—

	Lethal.
4·5-in.	34,250 per week.
60-pdr.	11,250 ,,

The decision to use the 6-in. howitzer for firing chemical shell came on 4 May. The War Office intended 6-in. lethal and lachrymatory shell to supersede 60-pdr. shell, and makers of 60-pdr. chemical shell were to be gradually changed over to 6-in., care being taken, however, that the combined output of 6-in. and 60-pdr. did not fall below 13,750 a week. As soon as the issue of 6-in. chemical shell reached this figure, the requirement for 60-pdr. would be confined to 1,000 a week for the East.

In May, 1917, there was an important change of policy, G.H.Q. deciding that only 75 per cent. of the chemical shell was to be lethal, and that the rest was to be lachrymatory.[2] In August, following on the use of mustard gas by the Germans, there were demands for this type of filling, but the necessity for prolonged research and experiment delayed the issue of mustard gas shell, and in spite of the urgent demand for the supply of this type of ammunition on an enormous scale, it was only just coming into bulk production at the date of the Armistice. A rapid development in the demand for chemical shell is a feature of the last year of the war, and the growth in the requirement appears from the programmes issued on 26 September, 1917, and 27 February, 1918 :—

	Smoke.	Chemical.	
		26 Sept., 1916.	27 Feb., 1918.
18 pdr. ..	20,000 (including 3,500 for the East)	—	—
4·5-in. ..	7,000 (including 1,000 for the East)	34,000	34,000
60-pdr. ..	.. ..	—	1,000
6-in. ..	.. ..	13,500	51,000
6-pdr. ..	.. ..	1,500	—

The later of these two programmes was distinguished by a revival in the demand for 60-pdr. chemical shell, while the demand for 6-in. chemical shell was trebled. Eighteen-pounder chemical shell filled with mustard gas (H.S.) was asked for on 19 December, 1917.[3]

[1] 121/1/230 in D.M.R.S. 296 A. [2] HIST. REC./H/1650/10, p. 87.
[3] D.M.R.S. 296 A.

During 1918 G.H.Q. constantly made urgent demands for artillery shell with chemical fillings[1] and a still further development of this form of warfare in 1919 was forecasted.[2] On 18 June, 1918, Mr. Churchill gave instructions that in regard to the provision of gun ammunition attention was in the first instance to be concentrated upon chemical shells.[3] The following were the weekly requirements of the War Office for the last six months of 1918[4] :—

1918.				1919.	
Nature.	Persistent.	Non-persistent.	Total.	Percentage of total requirements of shell for various natures of guns and howitzers which should be gas shell, in offence and defence respectively.	
				Offence.	Defence.
				Per cent.	Per cent.
18-pdr..	50,000	—	50,000	10	15
4·5-in. howitzer ..	22,500	7,500	30,000	15	22½
60-pdr.	20,000	7,000	27,000	20	30
6-in. howitzer ..	37,500	12,500	50,000	20	30
6-in. gun	4,000	—	4,000	20	30
8-in. howitzer ..	7,000	—	7,000	10	15
9·2-in. howitzer ..	6,000	—	6,000	10	15

Of the requirements for 1919, chemical shell for 18-pdr. guns, 6 in. guns, 8 in. howitzers, and 9·2 in. howitzers should all be filled with a persistent gas.

66 per cent. of 60-pdr. gas shells should be filled with a persistent gas and with 34 per cent. a non-persistent gas.

75 per cent. of 4·5 in. and 6 in. howitzer gas shells should be filled with a persistent gas and 25 per cent. with a non-persistent gas.

[1] 8 February, 121/1/391 in D.M.R.S. 296 A.
[2] War Office letter (8 May, 1918); Minutes of Co-ordinating Committee (14 May, 1918).
[3] Minutes of Co-ordinating Committee (18 June, 1918).
[4] Hist. Rec./R/1000/63, June, 1918.

CHAPTER II.

REVIEW OF THE CHIEF CHANGES IN THE DESIGN OF GUN AMMUNITION FOR LAND SERVICE, 1914–1918.

I.—Introduction.

Satisfactory gun and howitzer ammunition might be defined as ammunition which is safe and simple to handle, certain and effective in action, and weather-proof—*i.e.*, capable of being stacked in the field with the minimum of protection without deterioration over a period of several months. High explosive shell should give complete detonation on graze or impact, and other natures should function reliably as intended. All should be free from liability to blinds or premature action. Any considerable percentage of either blinds or prematures destroys the confidence of the men; the former also encourages the enemy, while the latter, if they occur in the bore of the gun, may involve the destruction of the gun-mounting and casualties both to the detachment and to the troops over whom fire may be proceeding.

Blinds are usually due to the failure of the fuse to function, and prematures to unsafe fuses and detonators and occasionally they are due to defective shell or fillings. Broadly speaking, it may be said that the failures with high explosive ammunition, which were a constant difficulty during the first two years of the war, were due to the fact that at the outset more shrapnel than high explosive ammunition was used by the British Field Army, that a really satisfactory fuse for high explosive shell did not exist, and that shortage of materials necessitated the adoption of new and untried explosive mixtures, the proper method of filling and detonating which had to be evolved by experiment.

When the war broke out all the high explosive shell in the British Army were filled with lyddite; there was no high explosive ammunition for the field gun and only a small proportion for the 4·5-in. howitzer. The proportions carried by the original Expeditionary Force were:—

100 per cent. shrapnel for the 18-pdr. and 13-pdr.
70 per cent. shrapnel and 30 per cent. H.E. for the 4·5-in. howitzer and the 60-pdr. gun.
10 per cent. shrapnel and 90 per cent. H.E. for the 6-in. howitzer.

The growing demand for high explosive ammunition was at first met by filling part of the supply of high explosive ammunition with pure T.N.T. which the Army had been on the eve of adopting as a standard filling on the outbreak of war, as it was safer to handle and not, like picric acid, liable to attack the metal of the shell fuses and to form picrates, which might cause prematures. As, however, it soon

became apparent that the supply of pure T.N.T. would be insufficient to fill the large quantities of high explosive shell that had been ordered, Lord Moulton's Committee experimented with mixtures of T.N.T. and ammonium nitrate, which had been put forward by the Research Department, Woolwich, and 40/60 and 80/20 amatol were gradually adopted as the standard fillings for gun ammunition for the British Army.

In order to make the best use of these explosives, modifications in shell design, in filling, and in the method of detonation had to be evolved, which necessitated elaborate experiments, hampered by the pressure for supply.

Since changes in design tended to delay manufacture there had to be a constant balancing between the efforts to obtain greater safety and efficiency by change of design, and the efforts to assist manufacture and economise raw material by minimising changes which dislocated output. Since only a fraction of the changes which affected the design of gun ammunition between 1914 and 1915 can be considered here, an attempt has been made to select only those changes which, by making service ammunition safer in use and more destructive in action, by simplifying manufacture or economising raw material, had a really important effect.

II.—Early Changes in Shell Design.

Between August, 1914, and June, 1915, some important changes in shell design were introduced with the view of meeting the difficulties of contractors who were new to shell manufacture.

Like all the rest of its equipment the ammunition used by the original Expeditionary Force called for a very high standard of workmanship. The limits of variation allowed were small, inspection was extraordinarily rigid, and the finished product was the work of highly skilled craftsmen, using steel of the finest quality. The necessities of the war and the demands of the new armies led to a gradual, but cautious lowering of this high standard, in order to make production in bulk by less highly skilled workers possible. It is interesting to notice that the Navy, strong in its command of the first call on the country's resources, has never allowed manufacturing difficulties to modify design.

(a) Introduction of H.E. Shell for Field Guns.

Though, at the outbreak of war, the Navy and Coast Defences used H.E. shell for all calibres, the Field Army only used it for the 4·5-in. howitzer, 60-pdr., and 4·7-in. gun. A certain amount existed, however, for the 6-in. howitzer (which also fired the 6-in. gun shell), and designs were ready for 9·2-in. howitzers and all guns above 60-pdr. The designs for shell for the heavier howitzers were got out in the early months of the war.

Before the war the general designs of H.E. shell showed a solid base, with a screwed-in base plate, a solid head with bottle nose, and a tapered cavity, the whole shell being made to fine limits of weight and dimensions.

The chief general changes in design during the early part of the war were the introduction for field guns of H.E. shell, which were made solid, with parallel walled cavities to facilitate block filling, and with screwed-in base plates. The taper walls usually employed (with a view to allowing increased capacity for bursting charge) were found difficult to manufacture under the new conditions of production, and parallel walled shell were introduced, partly to obviate this difficulty and partly to admit of block charges being used. This latter requirement also necessitated, in the case of shell above 18-pdr., either a screwed-on head or a screwed-in base adapter. The very small variations in weight allowed at the beginning of the war presented a formidable manufacturing problem when shell began to be called for in large quantities, and the weight tolerances had to be largely increased. In order to minimise ranging difficulties the device of stencilling the weight of the shell when filled on the body, which was the normal procedure before the war, was again put into practice, the shell being sorted into batches according to their varying weights.[1]

(b) INTRODUCTION OF BASE PLATES.

The object of base plates in H.E. shell is to avoid the danger of premature explosion through gases from the propellant penetrating the base of the shell by means of porosities due to piping.

Base plating was introduced for both Navy and Army in 1909,[2] and great care and attention was given to the fitting of the base plates. These were screwed in, and the fit in each case was guaranteed by the inspector's stamp. The fitting was highly skilled work, and owing to the shortage of skilled labour it was found about the end of 1914, that the rate at which base plates could be fitted was governing the output of shell. As a temporary measure only, base plates were dropped for 4·5-in., 4·7-in. and 60-pdr. shell and for certain shells made from ingots produced by Messrs. Hadfield's special process. It was realised that this concession was due only to the pressure of demand as extremely dangerous faults had been found in shells not fitted with base plates, faults which would be practically certain to cause detonation in the bore of the gun.[3]

Meanwhile, the shell makers were urging that screwing in the base plate was unnecessary and that riveting would be sufficient. This method, which was expected to halve the time and cost of production,

[1] Information given by Sir Glynn West.
[2] *Ordnance Board Minutes*, 1836.
[3] *Annual Report of President of Ordnance Board*, 1915, pp. 496-7.

was approved by the Design Department and universally adopted.[1] The Director of Artillery, therefore, gave instructions that all H.E. shells must be fitted with base plates (4 April, 1915),[2] and contractors were requested to begin fitting base plates within three months from 31 May.[3] There was great delay in carrying out this instruction,[4] and in October the War Office ordered that, in all cases in which base plates were not fitted, the shell must be made from steel forged from an ingot from which the discard had been parted cold, before forging.[5] As comparatively few steelmakers had the necessary plant for parting the discard from the ingots before forging, Mr. West renewed the general instruction that base plates were to be fitted to all H.E. shell. In December several contractors were still supplying some natures of shell without base plates.

After repeated warnings[6] the Design Department decided (9 June, 1916) that no more shell without base plates were to be accepted at home or abroad. At the same time, owing to the fact that several prematures had occurred recently with 4·5-in. shell, it was decided that no more of the non-base plated shells should be filled, and that the existing stocks of empty shell should be disposed of.[7]

III.—Introduction of the Amatol Mixtures.

The 40/60 amatol mixture was first used for supply in June, 1915, when 18-pdr. shell were filled with it at Woolwich. After this date the only 18-pdr. shell which were filled with unmixed T.N.T. were a comparatively small number which were filled with pure T.N.T. in paper cases. The use of the 80/20 mixture in the block form for filling 18-pdr. shell began about the same time, and in August the Chief Superintendent of Ordnance Factories began filling the larger natures with 40/60 by the melt process. It was originally proposed that the 80/20 mixture should be adopted for all H.E. shell ordered under the additional programme of July, 1915, and it was thought that the best method of using this mixture was to insert the filling into the shell in blocks. In order to make this possible the designs of shell had to be modified, the larger and smaller natures being treated differently. In the larger natures a screwed-in base adapter was used in order to allow the block to be inserted from the base, the smaller natures being made with a loose head and a solid base plate.[8]

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[1] 19 June, 1915. *Annual Report of President of Ordnance Board*, 1915, pp. 494-5.
[2] *Ordnance Board Minutes*, 14665.
[3] Contracts/S/7622. 75/12/8888, referred to in D.G.M.D./S/143.
[4] 94/S/630.
[5] 75/12/9187 (about 23 October). The copy of the War Office letter in D.G.M.D./S/143 is undated.
[6] D.G.M.D./S/143; 94/S/630.
[7] D.G.M.D./S/58.
[8] *Annual Report of President of Ordnance Board*, 1915, p. 499.

The block method of filling, however, was never used on a large scale in natures above the 18-pdr. A Commission sent to France to study French filling methods in the Autumn of 1915 reported in favour of filling by pressing. Early in November, 1915, the Chief Superintendent of Ordnancé Factories began pressing 80/20 into 18-pdr. shell by the one press method and soon achieved a considerable output, while Lord Chetwynd put up plant at Chilwell to press 80/20 into the larger natures, and began to deliver shells so filled in the spring of 1916, as well as shells filled with 40/60 from a separate melt unit.

As the difficulty of detonation increased with the proportion of ammonium nitrate in the mixture, it was decided that the use of 40/60 must be continued until a satisfactory system of detonating 80/20 had been evolved. The other filling factories erected by the Ministry therefore were laid out to begin with melt filling of 40/60 and to go on afterwards to filling 80/20 by pressing. They began filling 40/60 between April and July, 1916, and in the following Autumn began pressing 80/20, whenthe modified forms of fuse, gaine, and exploder container were beginning to come forward.

A final change in filling methods was the evolution and adoption of hot-mixed filling for the 80/20 mixture, the lay-out of 40/60 melt plant being gradually converted, from December, 1916, onwards, to one suitable for 80/20 hot mixed filling.

The abandonment of the scheme for block filling for large shell resulted in another change in shell design. The loose-headed shells were found to be unsatisfactory. Detonation was poor, and there were prematures owing to the explosive leaking into the screw-threads and being nipped on set-back. It was decided, therefore, that the loose heads for the smaller natures of shell should be done away with as soon as possible, and that the noses of shell should be bottled.[1] The larger natures of shell with screwed-in base adapters, although no longer necessary from the filling point of view on account of the abandonment of block filling for these natures, had to be retained, as the National Projectile Factories had been laid out with plant for their production, and were, therefore, insufficiently provided with forging presses to make the solid base type which was preferred.[2] The base adapters in these shell were riveted externally and internally, and the shell fitted with a pad impermeable to the oily exudation produced in some amatols.

Though alterations in the nature of the high explosive used had considerable effect upon the design of gun ammunition, it was found possible to adopt new forms of propellant without any important change in design being involved. The cordite used by the British

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[1] Information given by Sir Glynn West.

[2] The objection to base adapter shell owing to the exudation from the filling which occured in hot climates will be treated elsewhere.

Army at the beginning of the war gave very satisfactory results, but the introduction of alternative propellants was necessitated by a shortage of raw materials, nitro-cellulose powder from the United States being introduced into the service use during 1915.

Owing to the shortage of acetone, a new form of cordite—R.D.B. (or Research Department "B") composition—designed to give exactly the same calorimetic value and ballistics as British service cordite, but using ether alcohol instead of acetone as a solvent and a nitro-cellulose of lower nitration than gun cotton, was adopted. The manufacturing difficulties were overcome by December, 1915, and preparations were made for its production at the new factory which was then being built at Gretna. Later all the land service propellant factories, both Government and trade factories, made R.D.B. Nitro-cellulose powder was introduced to the Army before its moisture-absorbing properties were fully realised, and it was at first unpopular.[1] As soon as the necessity for keeping it protected from moisture (though not necessarily under air-tight conditions) was understood, and the method of packing and carrying the cartridges improved, complaints practically ceased, and N.C.T. proved to be the most regular propellant for all the charges used in howitzers when properly kept.

IV.—Prematures in the Autumn of 1915: Condemnation of the No. 80/44 Fuse and the Long Gaine.

The state of affairs in September, 1915, was very serious. There were a very large number of prematures with H.E. shell in France, causing loss of life and destroying the guns, and it was calculated that there was one premature to every 5,000 rounds of H.E. ammunition fired. Evidence at the military Courts of Enquiry showed that there was apparently no fault in the guns or in the service of the guns, and that the accidents were probably due to defective shells or fuses. Samples of the shells were tested by the Chief Superintendent of Ordnance Factories, specially examined for flaws, part sectioned and fractured through the base and cut up for mechanical tests of yield, breaking and elongation, and for analysis. On 10 December he reported that the shells were gauged and found correct, that on sectioning and fracture there were no traces of flaws or of piping, and that the base plates were correctly fitted. There was nothing in these tests to account for the failure of the shell. Microphotographs of the shell before and after normalising were also examined on the request of the Raw Materials Branch, and it was reported on 23 March, 1916, that the steel was quite satisfactory before and after normalising.[2]

The fault, therefore, did not appear to rest with shells similar to those tested, but at this period it is probable that there were still in France a certain number of old pattern shells, without base plates, for the 4·7-in. and 60-pdr. guns and for the 6-in. howitzer.

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[1] HIST. REC./R/810/8.

[2] *Ordnance Board Minutes*, 15,765, 16,027. *Ordnance Committee Minutes*, 143 (in D.G.M.D./S/28); D.M.R.S. 160, 216, 240.

The fusing and filling were also considered. Reports from the Army received in December showed that the amatol mixtures were not popular in the First Army, but, owing to the faulty fuse and the difficulty of good observation and the lack of experience, the Artillery Adviser at G.H.Q. stated that a definite opinion on its merits could not be formed.[1]

One of the drawbacks of amatol was the fact that detonation produced very little smoke, and since blinds and quality of detonation were usually judged partly by sight and partly by sound the use of delay in the fuse, particularly with howitzers, caused the sound to be muffled and reduced the amount of smoke seen, especially on soft ground, thus accounting for many rounds being reported blind or giving bad detonation which were really satisfactory. The increased use of aeroplane observation, from which amatol bursts were particularly difficult to see, also increased the number of shell reported blind which were probably not so.[2]

Up till 1916 the proportion of prematures with the 4·5 in. howitzer was larger than with other natures. The practice of firing the leather-board cartridge covers in the howitzer was believed by some to be the cause, but there was no direct evidence of this. The change, however, to rubber covers, which had to be removed before the cartridge would load occurred late in 1916, and the prematures decreased as the new type of cover replaced the old.

A report by the Artillery Adviser at G.H.Q., dated 30 December, 1915,[3] showed an average of one gun destroyed or damaged to 27,650 rounds of 18-pdr. H.E. fired. Colonel Lee pointed out that this figure showed an improvement as compared with the September battles,[4] but that it compared very unfavourably with recent French experience, which gave only one burst in over 100,000 rounds. Major-General Du Cane thought the improvement was due to improved manufacture, but Colonel Lee suggested that the changing over to No. 2 gaine and some minor improvements had greatly raised the factor of safety, and the percentage of prematures might be expected to fall considerably in the near future.

V.—Changes in H.E. Fuses.

At the beginning of the war there was, for land service, only one true direct action detonating fuse (*i.e.*, a fuse containing the mechanism to detonate on percussion its own H.E. magazine) suitable for use in the field. This was the No. 44 fuse. The No. 17 and Nos. 18 and 45 fuses were used to some small extent, but the former was powder-filled and could not be depended on to detonate H.E. shell, while the last two were altogether too insensitive for general use in the field, being fuses designed to function on armour plate, for use in Coast Defence equipments.

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[1] 74/6/3712. [2] D.G.M.D./F/05. [3] *Ibid.*
[4] 3 January, 1916, *Ibid.*

The No. 44 had recently been designed for use in howitzers and was of the general service gauge; it did not function at very low angles of elevation, but otherwise should have met the general conditions of land service warfare; actually in supply detonation results were often poor and it was not till nearly two years later that modifications to design and filling made it really satisfactory.

Meanwhile other designs had been brought into use. The 80/44 and 44/80 combination was the first. This was a temporary expedient to provide a way of bursting H.E. shell either in air or on percussion at will. The No. 44/80 was a No. 44 fuse fitted with a stronger shutter spring and with no safety pin. It was screwed into an adapter which fitted the fuse hole of the shell, and the No. 80/44 (which was the No. 80 slightly modified) was screwed in on top. The No. 44/80 fuse acted merely as a "gaine" to the T. & P. fuse which could be set as usual to give time or percussion action, and the ignition of its magazine fired and caused to detonate the No. 44/80.

The advantage of bursting H.E. shell in air against land targets became less apparent as the war went on, and the No. 80/44 and 44/80 combination was gradually relegated for use against aircraft, for which purpose the percussion mechanism was always removed. The combination continued to be used up to the end of the war, though in some cases the No. 44/80 fuse was replaced by a special adapter and gaine.

The graze fuse, No. 100 fuse with No. 1 gaine, was introduced in February, 1915, and was designed to provide an extremely sensitive graze action fuse that would function in any gun or howitzer at any angle of elevation, and yet required no preparation before firing. Fuse and gaine were issued as one unit, the action of the fuse being to provide a small flame that would bring to detonation the contents of the gaine.

In supply the No. 100 fuse was found unsatisfactory. Prematures that occurred in the gun or in flight, and, in at least one case, during rough usage, were put down at the time to the cocked spring which was a feature of this design.[1] The fault may possibly have been due to other causes, defective manufacture and so on, but the cocked spring system was taken out at the cost of a slight decrease in sensitiveness on graze action. Other small changes were made and the fuse thus modified was called the No. 101 (introduced in May, 1916), which gradually replaced the No. 100.

The transition period between the No. 100 and No. 101 fuses was covered by converting existing No. 100 fuses to Nos. 102 and 103, the latter fuses having the cocked spring device omitted. The No. 103 fuse was short and did not itself carry the gaine which was supported instead in a separate adapter screwed into the mouth of the shell.

[1] The fire at Rouen was started by the explosion of one of these fuses which was accidentally dropped. Reports by General Du Cane. 7 February 1916. Hist. Rec./R/900/7.)

This combination gave excellent results and persisted till the end of the war as it facilitated production, but the system was inferior as regards cost of manufacture and ease of filling to one where fuse and gaine form one unit.

The first gaine issued (No. 1) was long. It not only proved to give variable and often poor detonation with amatol, but was also found to be too heavy, and so fell under suspicion of causing prematures owing to its tearing away from the fuse on shock of discharge. The No. 2 gaine was therefore introduced. It was shorter, lighter, and was fitted with a large fulminate detonator to improve the detonation of amatol.

Results with the No. 100 fuse and the No. 2 gaine were undoubtedly superior both as regards safety and detonation to those obtained before but prematures were still unpleasantly frequent. It was thought that prematures were caused by the shock of discharge firing the fuse detonator, either directly, or by the breaking away of the needle of the fuse. Screwed needles were then introduced and centrifugally operated shutters were placed between the fuse detonator and the gaine.

Complaints were still frequently made that the No. 100 and No. 101 type fuses gave very bad results in the field. This was largely due to the fact that a graze action fuse had an inherent delay which was sufficient to allow the shell to bury itself to some extent in the ground before detonation so that both the sound and effect were muffled. Good shell might therefore readily be reported as giving poor detonation or blinds.

Difficulties of this kind showed the value for all purposes when above ground effect was required of a D.A. fuse which would act before the shell had penetrated the surface. The introduction of the No. 106 fuse is referred to in a later section.[1]

VI.—New Methods of Filling.

A new method of filling shell had also to be adopted at the beginning of 1916 in order to obtain satisfactory detonation with amatol 80/20. The Ordnance Committee recommended that block filling of larger natures of shell than 18-pdr. should be given up, and that all natures of shell should be filled by pressing, the larger natures being filled on the lines adopted in France.[2] Certain precautions in the filling of shell had been established by the Research Department, Woolwich, as essential to secure good detonation. One of these was the necessity for maintaining contact between the gaine and the exploder at the time the projectile reached its target. This was secured by having

[1] See below, p. 55.
[2] D.D.G. (A) 14321; information given by Sir Glynn West; (Printed) *Weekly Report*, No. 22, VI (25 December, 1915).

the exploder under compression. In the case of shell, 4·5-in. and above, compression was maintained irrespective of any movement of the main charge by the use of a metal sleeve screwed into the fuse hole. This metal sleeve or exploder container also sealed the shell against the entrance of moisture, and was evolved by the Research Department, Woolwich, in conjunction with the Chief Superintendent of Ordnance Factories. In addition the impulse given by the exploder was augmented by surrounding the sleeve with T.N.T. The metal exploder container was adopted in December, 1916.[1] A few intermediate designs had to be got out again as an emergency measure, in order to enable Lord Chetwynd's factory to fill and finish off shell filled with 40/60 or 80/20 pending the delivery of shell suitable for the exploder container.[2] The consequent modifications in empty shell and components involved considerable delay. Though steel exploder containers, and shells with threads of the fuse hole sufficiently deep to take the exploder container, were being made in April, 1916, and designs had been approved for shell of this type for all natures from 4·5-in.[3] upwards, the supply did not meet the programme in September, 1916.[4] Eighteen-pounder high explosive shell and smaller natures were not to be fitted with an exploder container, but were to have a centre block of pure trotyl.[5]

VII.—New Shell Designs.

The 18-pdr. H.E. shell remained practically unchanged throughout the war. A design for a shell with a larger capacity, and fitted with an optional delay fuse, was tried experimentally, but as this required forging plant which was not available, and, moreover, would not have packed in existing limbers and wagons, it was not proceeded with.[6]

The 18-pdr. shrapnel shell also remained unchanged for most of the war, but owing to a certain number of prematures attributed to break-up of the shell, and the difficulty of getting steel of the required quality, a new design was introduced which could be made of a lower grade steel and consequently entailed a slight loss of bullets. This was introduced in 1917 and was found to be satisfactory.

The 13-pdr. shell, both H.E. and shrapnel, remained the same throughout the war.

At the beginning of the war there were two types of 6-in. howitzer shell, weighing 120 lb. and 100 lb. respectively, and the 100-lb. gun shell was also used. The 120-lb. shell was not made during the war,

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[1] Information given by Sir Robert Robertson.

[2] Hist. Rec./R/900/7. Throughout January trials of different methods of filling and of the comparative efficiency of the various amatol mixtures, 60/40, 40/60, 70/30 and 80/20 were going on. (Printed) *Weekly Report*, No. 26, VII (22 January, 1916).

[3] (Printed) *Weekly Report*, No. 40, III (6 May, 1916).

[4] 74/H.E./1257.

[5] (Printed) *Weekly Report*, No. 29, VII (12 February, 1916).

[6] Hist. Rec./R/1350/50.

but existing stocks of it were used up. These and the stocks of 100-lb. gun shell were soon exhausted, and, as the latter was unnecessarily strong for the howitzers, new howitzer shell of 100 lb. weight, with thinner walls and an increased bursting charge, were designed, and adopted in February, 1916.[1] There were two types of the new pattern, one with a screwed-on head, the other with a bottled nose.[2] The latter was the design most favoured by the authorities, but as it was slightly longer than the existing type it could not be produced from existing forgings. The bottled type of shell proved to be superior and at the end of 1916 all manufacturers were instructed to change over to that type.[3]

The introduction of all these changes during the first six months of 1916 had a hampering effect upon supply,[4] especially in view of the great efforts that were being made to produce large quantities of gun ammunition for the coming offensive, but they resulted in a great improvement in the quality of high explosive ammunition.

On the other hand, many minor changes were made during the war with the special object of assisting supply. In General Du Cane's words the Design Department were " the custodians of the interests of the Army as regards the safety and quality of the munitions supplied by the Ministry." It was necessary, therefore, for him to press for design modifications, but he proposed to consult the supply departments at every stage and consider the effect on output in all its bearings—except when a change of design was necessitated in order to make the munitions safe in the field.[5]

VIII.—Changes in Design of Chemical Shell.[6]

Though a small number of shell of the ordinary high explosive type had been sent out to France filled with liquid chlorine at the end of 1915, the first chemical shell for artillery to be supplied in bulk was the 4·5-in. howitzer shell in cast-iron, which was issued in February, 1916.[7] Early in 1916 the substitution of a steel shell was being considered, and designs of steel lachrymatory shell for both the 4·5-in. howitzer and the 60-pdr. gun were recommended by the Ordnance Committee (19 February) for manufacture in anticipation of trial.[8] The new designs contained a double diaphragm and allowed

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[1] 94/S/2499. (Printed) *Weekly Report*, No. 28, VII (5 February, 1916).

[2] The effect on the supply department of the change from existing marks, Marks XV and XVI, to the new patterns, Mark XV (A) and Mark XVI (A), later known as Mark V and Mark VI, will be considered elsewhere.

[3] For details, *see* Vol. X, Part III, Chap. II.

[4] HIST. REC./R/1340/50.

[5] HIST. REC./R/900/7.

[6] A more detailed account of these changes will be found in HIST. REC./H/1650/9, I, pp. 102–6, pp. 50–135.

[7] *See* above p. 35.

[8] (Printed) *Weekly Report*, No. 29, VII (12 February, 1916); *Ordnance Committee Minutes*, 1239.

the insertion of a smoke-producing mixture in addition to the bursting charge in the head of the shell.[1] A little later simpler designs for lachrymatory shell for the 6-in. gun or howitzer, the 60-pdr. and 4·7-in. guns were approved (28 March), and these shells were suitable for other chemical fillings as well as S.K.[2] The Ordnance Committee was then asked to prepare designs for 8-in. and 9·2-in. gas shells on similar lines.[3] On firing trials it was found that the No. 101 fuse, with its inherent slight delay, did not act quickly enough, with the result that as the shell had time to penetrate into the ground, the chemical effect was lost.[4] The No. 44 fuse was therefore used instead,[5] the No. 106 fuse being substituted later on.

All the designs hitherto approved were steel shells with a double diaphragm, but with the view of adapting existing H.E. shell for chemical filling, it was suggested in May, 1916, that a steel container, made from rejected 18-pdr. H.E. shell, might be fitted in the nose of the shell. Pending further trials, Mr. West was given advance information to enable him to make preliminary arrangements for manufacture.[6] A typical design of this container shell, converted from H.E. shell, was approved about 20 May, for S.K. (lachrymatory) filling only. Trials with suitable cements for sealing the container threads when other chemical fillings were used followed,[7] and kaolin-silicate cement was adopted to seal both the container and the double diaphragm type of shell (12 September).[8] This gave excellent results.

On 26 May, 1916, a design for the conversion of rejected 4·5-in. H.E. Mark V shell to a container type for chemical filling was approved.[9] The Birmingham National Shell Factory was turned over to this class of shell, and it was arranged that rejected 18-pdr. H.E. shell should be obtained from contractors in the Birmingham area and converted into containers for the 4·5-in. chemical shell.[10]

The 4·7-in. and 60-pdr. chemical shell with steel container were tried at first with a bursting charge of powder, but the results were unsatisfactory and it was decided that these shells like the 4·5-in. and 6-in. designs should be filled with H.E.[11] The designs for these two natures of chemical shell were approved on 24 July,[12] and a container design for 4·7-in. shell was approved soon afterwards.[13]

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[1] D.D.G. (A), 17138.
[2] (Printed) *Weekly Report*, No. 33, VII (11 March, 1916).
[3] *Ibid.*, No. 39, XIII (29 April, 1916).
[4] *Ibid.*, No. 41, XII (13 May, 1916).
[5] *Ibid.*, No. 87, II (14 April, 1917).
[6] *Ibid.*, No. 41, XII (13 May, 1916).
[7] *Ibid.*, No. 42, XII. (20 May, 1916); *Ordnance Committee Minutes*, 3898; D.G.M.D./S/067; D.G.M.D./S/544.
[8] *Ordnance Committee Minutes*, 7564.
[9] D.G.M.D./S/29; D.D.G. (A). 11963.
[10] D.A.O. Committee Minutes (filed at Archives Registry).
[11] (Printed) *Weekly Report*, No. 44, XII (3 June, 1916.)
[12] *Ordnance Committee Minutes*, 6068; D.G.M.D./C/561.
[13] Hist. Rec./H/1650/9, II.

The supply department pressed that the double diaphragm design should be given up owing to difficulties in manufacture, but the Design Department refused as its effect was far better than that of the container shell.[1] Further, the diaphragm type was the only design which was approved for phosgene filling, though jellite could be used in the container shell.[2] In August, however, there were difficulties with the double diaphragm type, owing to leakage at the diaphragm and the desirability of doing away with the diaphragm type was again discussed. Since, however, there was no doubt but that the diaphragm type was more effective from the military point of view, the Ordnance Committee arranged to meet the Chemical Advisory Committee to consider the question.[3] Both types were retained in the service, the container type for conversion from H.E. shell and the double diaphragm for new shell. In August, 1917, after experiments dating from December, 1916, designs of cast-iron shell, similar to the original 4·5-in., were introduced for use with lethal fillings in the 60-pdr. gun and the 4·5-in. and 6-in. howitzers, as it was found that the force of the explosion necessary to open a steel shell dissipated the filling and deprived it of its lethal effect. The adoption of cast-iron also eased the shortage of steel, which was urgently required for H.E. shell.

Precautions were taken to prevent leakage of the chemical from the double diaphragm shell by cementing the lower diaphragm with kaolin-silicate cement, plugging an air escape hole and so on (12 September, 1916).[4] A little later, on 21 November, it was decided that the double diaphragm type was to be used for S.K. or W.P. fillings only,[5] but this decision had to be reversed owing to the difficulty of obtaining a sufficient supply of other types of shell (November, 1916).[6]

The variation in the weight of chemical shells according to the nature of their filling created serious ranging difficulties, which had to be overcome by bringing the filled shell to a mean weight within 1 per cent. of the standard weight by means of shot.[7]

Subsequently container shell became universal, since it was found that riveting the container and filling through a hole in the side (closed by a steel plug) was efficient. Such a design had the advantage that it admitted of air testing of the joint before filling, and shell were brought to weight by means of wooden or cast-iron discs fitted inside the container, the proportion of each depending on the specific gravity of the chemical to be used.

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[1] 27 July (Printed) *Weekly Report*, No. 52, XII (29 July, 1916).
[2] 29 July, 1916 ; C.R. 038.
[3] (Printed) *Weekly Report*, No. 56, XII (26 August, 1916).
[4] *Ordnance Committee Minutes*, 7564.
[5] *Ordnance Committee Minutes*, 10136.
[6] HIST. REC./H/1650/9, II, p. 69.
[7] *Meeting of Ordnance Committee* (20 September, 1917).

IX.—Smoke Mixtures for Observation Purposes.[1]

Trials which dated from September, 1915, when the Commander-in-Chief in France drew attention to the difficulty of observing from the air the bursting of H.E. shell, were carried out with a view to obtaining a suitable smoke with H.E. shell. The introduction of the amatol mixtures increased the difficulty of observation, and the subject was before the Ordnance Board and the Ordnance Committee until March, 1916. About 21 March the Ordnance Committee recommended that a phosphorus smoke box should be inserted in all H.E. shell, and a design was approved on 5 May. Pending an adequate output of shell giving smoke, powder-filled shell were to be used for ranging purposes. A phosphorus smoke box was specially necessary for long range gun shell—4·7-in., 60-pdr. and 6-in.—for counter battery work,[2] and on 29 April General Du Cane urged that the supply of it should be hastened and that experiments should be made with other substances besides red phosphorus, the supply of which was limited, and which was used in large quantities by the Trench Warfare Supply Department for smoke bombs and Stokes gun shells, as well as by the Admiralty and by the match trade.[3] There was also a difficulty in producing the special containers needed to prevent the amatol being contaminated by the phosphorus, which would have involved a risk of prematures.[4] The situation was serious, as if G.H.Q. insisted on the smoke box being inserted in a very large number of shell it would limit output. It was possible that, in view of the large stocks existing, the production of smoke grenades might be restricted in order to release phosphorus for shell. Powder-filled shell might be a satisfactory makeshift for ranging purposes.[5] A satisfactory substitute for phosphorus was found in July, when a trial with 60-pdr. amatol shells with a smoke mixture of potassium nitrate and aluminium (in the proportion of 70 to 30) gave very satisfactory results.[6] The use of this new mixture, which was inserted in a batiste bag in pressed fillings, was approved on 13 July, 1916.[7]

A little later another smoke mixture, consisting of 25 per cent. of 80/20 amatol and 75 per cent. of aluminium powder, was approved and this mixture was used with all poured fillings until the end of the war.[8]

Requests for the introduction of a smoke mixture in 4·5-in., 6-in., 8-in. and 9·2-in. shell and chemical shell with a high explosive burster

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[1] The demand for smoke shell for screening purposes has been treated in Vol. X, Part III, Chap. III.

[2] Letter from G.H.Q., 19 April (D.M.R.S. 376).

[3] Report by General Du Cane, 25 May, 1916.

[4] Hist. Rec./H/1520/6, p. 17.

[5] C.R. 4495.

[6] The trial was on Salisbury Plain on 4 July.

[7] D.G.M.D./S/298, 626, 865; *Ordnance Committee Minutes*, 7096; (Printed) *Weekly Report*, No. 48, XII (1 July, 1916), No. 50, XII (15 July, 1916).

[8] See *Fourteenth Report on Amatol*, by Dr. T. Martin Lowry (Hist. Rec./R/1520/7), for details of the various smoke mixtures.

came from G.H.Q. on 24 June, 1916.[1] The Canadian Corps had complained of the difficulty of observing the burst of 8-in. amatol shell and of the time wasted in trying to register on targets.[2] It was realised that owing to the scarcity of aluminium it would be difficult to provide a smoke mixture for this extended programme unless the experiments then in hand for the reduction of the amount of aluminium used in the production of ammonal were successful (31 July, 1916), and the issue of a percentage of powder-filled shell for observation purposes was recommended as a temporary expedient.[3] In August a new smoke mixture containing no aluminium and consisting of 70 parts of 80/20 amatol to 30 parts of ammonium chloride, was introduced and was approved on 23 February, 1917.[4] It was used for shell filled with 80/20 amatol (pressed) and was a great improvement in that it enabled smoke mixtures to be poured into the bottom of the shell filled by pressing without any bag or container.

In 1917 smoke mixtures were provided for 12-in. and 15-in. high explosive shell.[5]

X.—Introduction of the No. 106 Fuse.

The No. 44 fuse was still giving unsatisfactory results at the beginning of 1916 and the D.A. No. 106 fuse was therefore introduced (July, 1916). It was designed to give above ground effect and to act at lower angles of elevation than the No. 44, also to be as simple to fill and as certain in giving detonation as the No. 18 fuse. This was done at the sacrifice of the safety given by a shutter device. Trials were most satisfactory and further trials with a modified No. 44 of 2-in. fuse hole gauge were not proceeded with, though results with this design had also been very good.

The popularity of the new fuse was immediate, detonation was good, bursts were easily seen, and its results in wire-cutting were excellent. Prematures, however, still occurred,[6] and usually caused the destruction of the gun, so that the No. 106E. fuse was introduced to replace the No. 106 fuse. The No. 106E. was the No. 106 fitted with the safety shutter of the No. 44 type and was, therefore, just as difficult to fill as the latter fuse. Its power of initiating detonation with certainty when filled under service conditions had not been fully established at the end of the war.

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[1] D.G.M.D./S/626; (Printed) *Weekly Reports*, No. 39, XIII (29 April, 1916), No. 40, XIII (6 March 1916).
[2] 5 May, 1916, D.M.R.S. 376.
[3] D.M.R.S. 376.
[4] *Ibid.*
[5] *Ibid.*
[6] *Meetings of Ordnance Committee* (4 October, 1917, 8 November, 1917, 6 December, 1917).

XI.—Prematures with 18-pdr. Shell in November and December, 1916.

At the end of 1916 there were a number of prematures at proof of 18-pdr. shell. Suspicion fell upon the detonators of the fuses (No. 101) and of the gaines (No. 2) which appeared to be abnormally sensitive, and at a meeting held on 17 November, at which the Ordnance Committee, the Research Department, the Inspection Department, the Filling Department, and the Ordnance Factories were represented, it was decided that all detonators which had been re-pressed or re-formed should be withdrawn and that no re-forming of 10-grain gaine detonators should be permitted in future.[1]

At the same time, prematures occurred at gun proof of No. 101 fuses and gaines filled at the Coventry National Filling Factory (F.10), and on examination it was found that in many cases the gaine detonators were upside-down.

The issue of 400,000 fuses and gaines filled at this factory was suspended pending further examination[2] and Colonel Stansfeld suggested that a gauge should be employed, as at Perivale, to show whether the detonator was the right way up or not. There was evidence that unduly sensitive detonators had been supplied by Messrs. Kynoch and Nobels, the Elswick Ordnance Company, Messrs. Harding Wace and Company, Messrs. George Kent and Company, and the Abbey Wood National Filling Factory (F.11).

On the following day, 21 November, General Bingham reported that a number of prematures had occurred at the front and that seven guns had been destroyed.[3] On his instructions, telegrams were sent to all factories filling gaine detonators to the effect that the re-pressing and re-forming of all detonators must be stopped at once. As investigations seemed also to show that the chief cause of these prematures was some defect in the fuses filled at the Coventry National Filling Factory (Messrs. White and Poppe), the use of ammunition containing these fuses (about 1,500,000) was prohibited on 30 December.[4]

The trouble with these fuses was thought to be due to a large extent to unduly sensitive fuse detonators supplied by Messrs. Kynoch, and on 20 December the contract with that firm for 1·7-grain fuse detonators on which about 20,000,000 had already been supplied, was cancelled. The Ministry explained that their method of priming these detonators in non-danger buildings was not considered suitable.[5]

The trouble with these fuse detonators was partly due to the fact that no adequate specification for the mixture to be used existed, and to faulty inspection which enabled detonators to be issued in great

[1] D.D.G. (O) 866.
[2] Meeting on 20 November, D.D.G. (O) 566.
[3] 75/12/9436 in D.M.R.S. 428.
[4] D.M.R.S. 428.
[5] D.D.G. (O) 866.

numbers in a dirty condition, with fulminate composition on the outside of the shell, inadequately filled, not properly closed, and with loose and imperfect discs and washers.[1] A proper specification was issued and inspection was tightened up.

Special drop-tests were introduced at Woolwich, and Messrs. White and Poppe were instructed to issue no more 1·7-grain detonators until this test had been carried out. The factory protested against the introduction of new tests which disorganised production:—"It is impossible to control labour if output is continually held up in this casual manner. It is quite impossible to carry on in existing circumstances."[2]

A thorough reorganisation of the factory followed, and on 7 February it was decided that all the fuses and gaines filled at this factory prior to its recent reorganisation should be emptied and refilled, and the factory was in future to be known as Filling Factory No. 21, as the troops were naturally prejudiced against ammunition marked F.10.[3]

These fuses, however, were clearly not responsible for the whole of the trouble, for on 24 December G.H.Q. reported that although issue of the suspected ammunition had ceased since 24 November there had been a steady increase in the percentage of prematures with 18-pdr. ammunition, the proportion in the last fortnight being one premature in less than 20,000 rounds. Nearly all these prematures had occurred in the bore, resulting in the destruction of the gun and, in most cases, of the carriage also. Since 1 November there had been 91 casualties as a result of these prematures, which destroyed the confidence of the troops in their weapons. The seriousness of the situation was enhanced by the fact that a large proportion of the ammunition received was being accumulated with a view to future operations, and it was impossible not to contemplate with some anxiety the situation which might arise in the future during a period of intense fighting.[4]

The difficulty of obtaining satisfactory evidence as to the causes of these prematures was great. It was impossible for an 18-pdr. battery to examine every round and note its particulars before firing, and any attempt to sort ammunition into makes or lots was prohibited by the enormous variety contained in each consignment from home. In a large number of cases the evidence disappeared with the premature, and there was the further difficulty of obtaining particulars from batteries in the front line, "whose attention was rightly concentrated upon other matters."[5] G.H.Q. urged that the prevention of these prematures should not be entirely dependent upon reports rendered from France, that it was the primary duty of the Ministry of Munitions to ensure that the ammunition supplied should be satisfactory and safe to fire, and that no responsibility for this could rest on a Commander in the field.

[1] HIST. REC./R/1320/10, p. 4.
[2] 2 January, 1917.
[3] D.M.R.S. 428.
[4] 75/12/9436.
[5] 75/12/9436 in D.M.R.S. 428

XII.—Improvement in the Quality of Gun Ammunition.

The prolonged experiments to produce satisfactory detonation with high explosive shell and increased experience in manufacture and filling resulted in the production of ammunition of a high quality by the Spring of 1917.

On 27 September, 1916, in reply to a communication from the Army Council (31 August) reporting that there were still a number of cases of shells of various natures bursting prematurely either just outside or inside the bores of guns and howitzers in France,[1] the Ministry summarised the steps that had been taken to reduce the number of prematures:—

"(1) Increasing the number of tests of shell, especially those of Canadian manufacture, with a view to reducing prematures due to defective shell.

"(2) The introduction of a shutter in the cavity at the head of the gaine.

"(3) Increased knowledge and experience had resulted in the filling of shells being carried out more uniformly and the liability of any being incorrectly assembled had been thereby reduced.

"(4) Judging from the extensive trials carried out in the 4·5-in. howitzer the introduction of No. 106 fuse into the service should greatly reduce the percentage of prematures with this equipment, which had been reported with fuses of No. 100 type."

The introduction of the shutter in the No. 101 type and of the No. 106 fuse in any quantity would,however, take considerable time.

In a letter of 25 April, 1917, Sir Douglas Haig brought to the notice of the Army Council—

> "the extremely good performance of artillery material including guns, howitzers, and ammunition during the recent heavy fighting.
>
> "All natures of equipment have stood the strain of prolonged fighting most satisfactorily and the number of guns and howitzers out of action at any one time have been very small. No defects of serious importance have come to light.
>
> "The ammunition has also been satisfactory. Detonators have been good, blinds few, and prematures though not entirely eliminated, have shown a most satisfactory reduction in proportion to the number of rounds fired.
>
> "The actual number of prematures in the 18-pdr. gun during the period, 1 April to 15 April, was four, which worked out at one premature to every 317,000 rounds of H.E.

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[1] 75/12/9405 in D.M.R.S. 428.

"The corresponding figure for the 4·5-in. howitzer during the same period is seven prematures, or one in 108,000 rounds. In January last the proportion was one premature in 18,000 rounds.

"The No. 106 fuse has proved most valuable and by its action when used against wire, has contributed in no small degree to the success of the operations."

Later reports from the field were equally satisfactory. On some unfortunate occasions when British troops came under the fire of some of their own guns and shells which had been captured by the enemy, they reported that British high explosive shell showed a marked superiority over German.[1] The satisfactory detonation obtained with all types of H.E. shell in 1917 and the great improvement as compared with 1916, are shown by proof results, which by September, 1917, had reached a constant and high level of efficiency whether the shells were filled with picric acid, 80/20 or 40/60 amatol.[2] Difficulties arising from the peculiar tendency to exudation in shells filled with the lower proportions of ammonium nitrate led to the preference of 80/20 over 40/60, and the general change to 80/20 amatol for Land Service shells was facilitated by the conversion of the melt plants in filling factories to filling with hot mixed 80/20 amatol. During the year 1918 the results thus attained enabled the Army to abandon gradually the use of picric acid, which was costly to make and involved a high proportion of imports.

A report made after a visit to France by Colonel Galloway and Colonel Howarth of the Inspection Department (January, 1918), showed that the quality of the ammunition supplied by the Ministry left little to be desired. The leakage of existing designs of chemical shell could be regarded as practically non-existent, the adoption of a riveted type of container for the bursting charge during the Autumn of 1917 having obviated the risk of leakage through the head. There had been a few prematures with the No. 106 fuse, but there was little doubt but that these were due to tampering with the tapes and hammers at battery positions, and no single premature with this fuse had been traced to faults in filling.

As a result of this visit the Inspection Department urged that closer contact with the Ordnance Department in France was desirable and that it should not be necessary for communications to proceed through the War Office. The Gun Ammunition Filling Department was also anxious for closer contact with the troops in the field.[3]

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[1] Report by General Bingham, April, 1919 (HIST. REC./R/1000/89).

[2] *Ordnance Committee Minutes*, 23,437 ; M.C. 372.

It should be noticed that the difficulties with 80/20 amatol had been completely overcome by September, 1917, when shells filled with this mixture were giving 99 per cent. of detonations.

[3] Minutes by Colonel Hay to Colonel Milman, 31 January, 1918. The whole question of liaison with the Army is treated in more detail elsewhere. See Vol. IX, Part II, Chap. VII.

During the German advance in the Spring of 1918 the results reported from the field were, for a time, less favourable. On 7 May, 1918, a minute from the Minister drew the attention of the Design Department to the fact that though the proportion of prematures in high explosive shell was supposed to have fallen to one in 500,000 two months previously, artillery officers had reported it as much higher, even as high as 2 per cent. The Controller of Munitions Design in his reply attached a table showing that the percentage of prematures to the total number of H.E. fired was ·00077 per cent. :—

January	1 in 300,000 rounds.
February	1 in 170,000 rounds.
March	1 in 270,000 rounds.
April	1 in 90,000 rounds.

The comparatively high figures for April could be explained by the fact that the number of rounds fired was probably much underestimated owing to the disorganisation due to the German advance.

On 20 June, 1918, there was a report from France that the proportion of prematures in 18-pdr. shrapnel was between 2 and 3 per cent., the fault being due to the shell itself, not to the fuse, as pieces picked up showed grooves cut by the rifling of the gun barrel. It was probable that only those prematures which caused casualties or damage to the guns had been reported, so that the true figures had not been shown.

The Minister at once took the matter up and asked the Design Department to report on the causes of these prematures. There were several possible causes :—

(*a*) The failure of the cast-iron fuse socket—only 2,000,000 had been made, so the trouble would automatically cease.

(*b*) Failure of the fuse.

(*c*) Defective shell—a stronger pattern had been approved in May, 1917, but the earlier type was still in the field.

(*d*) Mistakes in fuse setting.

(*e*) Occasional fuse prematures.

Eighteen months previously, in order to economise brass, a cast-iron fuse socket had been adopted. At proof there were prematures, owing to the collapse of the cast-iron socket, so it was decided that no more should be made and brass should be reverted to at any cost. About 1,000,000 had been issued to the service, and as there had been no prematures at the beginning of manufacture, owing probably to good quality cast-iron being used, these were left in service. As soon as news was received that there had been prematures at the Front, the War Office wired instructions that no more were to be used.

It was possible that some of the fuses themselves might be defective, but special orders had been given about fuse inspection. A more probable cause of failures was that the fuses had been incorrectly set. It was understood that men fighting for hours in gas masks found it

difficult to set fuses correctly and the only means of surmounting this difficulty was an automatic fuse setter, which would be provided as soon as possible. This was a temporary set-back. The general quality of the ammunition supplied was very satisfactory, as in June, 1918, it was reported that there had been no casualties to personnel and very few to guns, as a result of prematures.

XIII.—Efforts to Increase Range.

(a) LENGTHENING OF THE SHELL HEAD.

The chief design problem of 1917 and 1918 was to increase the range of gun ammunition[1] by various expedients, such as lengthening the head of the shell by means of ballistic caps, or altering the shape of the shell and giving it a stream-line base. Simultaneously time fuses giving a longer range had to be evolved.

The attention of the Ministry had been directed to this subject since the Spring of 1916, and the first attempts to increase range took the form of lengthening the head of the shell.[2] In February and March, 1916, the Commander-in-Chief asked for a supply of 6-in. and 9·2-in. shrapnel shell with 4-calibre radius heads and long-burning time fuses. It was thought that the 9·2-in. shell would be of great value when used with the 9·2-in. guns on railway mountings at the longest possible range against large formations of men, collections of huts,[3] etc., and the Ministry was asked to undertake a supply of this shell provided its production did not react on the supply of ammunition of other natures for the 9·2-in. guns.

The design for the 6-in. gun shell with 4 c.r.h., was approved by the end of March and the 9·2-in. 4 c.r.h. shell by 6 May.[4]

The tendency to lengthen the head of the shell increased, as it was found to increase the range to a marked extent. Shells with 6 c.r.h. were adopted for many natures and 8 c.r.h. for the 60-pdr. shell during 1917,[5] and on 22 April, 1918, the War Office asked the Design Department to lengthen the range of the 9·2-in. gun by producing an 8 c.r.h. shell.[6]

(b) BALLISTIC CAPS.

The ballistic cap—a false nose screwed on to the top of the shell in order to lengthen its range—was first used for the 9·2-in. shell, a design giving an 8 c.r.h. being approved on 18 November, 1916,[7] manufacture on a small scale beginning soon afterwards. Designs for

[1] The guns themselves were also being modified in order to lengthen their range. See Vol. X, Part I.
[2] See above p. 28.
[3] O/82/31 in 121/Stores/4850. An earlier letter (O/B/390) of 23 July, 1915, was referred to, C.R.4428.
[4] (Printed) *Weekly Reports*, No. 36, VII (1 April, 1916); No. 40, XIII (6 May, 1916).
[5] *Meeting of Ordnance Committee* (18 October, 1917).
[6] D.M.R.S. 404.
[7] *Ibid.; Meeting of Ordnance Committee* (24 August, 1916).

6-in. shell and for 12-in. shell were produced later on, but the 6-in. shell fitted with a ballistic cap proved unsatisfactory owing to its inaccuracy and reliance was placed on the 6-in. 4 c.r.h. shell for long range purposes. Ballistic caps were not used for the smaller natures of shell. Many difficulties combined to retard the use of ballistic caps on a large scale. They were difficult to make, and on account of rough usage in transport, it was impossible for shells to travel with their caps on, which meant that the shell had to be fitted with its cap in the field, after it was fused, which could only be successful if the caps were interchangeable. Further, until the mechanical time fuse was produced, only H.E. shell fitted with graze fuses could be used. On 16 June, 1918, the Commander-in-Chief complained of the delay in producing shell with ballistic caps, which were used by the Germans with great success. They had, for instance, a long range gun of 15 cm., firing shells fitted with false caps of 10 c.r.h., and they were accurate at 25,000 yds. range. On measurement it had been found that in a series of rounds fired at 22,000 yds. the mean error was only about 45 yds. The enemy was undoubtedly superior in accurate long range and this was attributable to their improvements in rifling, driving bands, and contour.

> " It is clear," he wrote, " that we are wasting the power of our guns if we have not got the most accurate and long-ranging shell. If we were supplied with them, we could either obtain the same range as at present with a smaller charge and a consequent longer life to the gun, or for the same life of gun as at present we could obtain a longer range. It is, therefore, hoped that every endeavour will be made to increase the accuracy of range of our guns and howitzers. There should be no cessation in research and no finality in design."

It appeared, however, that most of the German increase of range was obtained by increased elevation or lengthened guns, obtained by producing new equipments, not by altering the shell only.[1]

The Design Department and the Ordnance Committee[2] thought there were many objections to the ballistic cap, and that the increase in range would be paid for in loss of mobility, loss of accuracy, smaller destructive power, and complication of supply in the field, while as far as the howitzers were concerned, there would not even be a great increase of range. With the high velocity howitzer there might be an increase of 800 yds. in range, but with the low velocity howitzers it would be less. Moreover, an instantaneous fuse must be used with a capped shell and a suitable one did not exist. It would be necessary, therefore, to use a graze fuse which would not produce good results owing to the slight inherent delay peculiar to its type. The No. 44 fuse under a cap had not been a success in France, but it was found, after experiment, that a sensitive fuse could be used with a false nose by means of a wooden stick extending from the fuse inside the false nose and projecting about an inch beyond it.

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[1] *Ordnance Committee Minutes*, 6358.
[2] *Meeting of Ordnance Committee* (17 August, 1918).

By the date of the Armistice, capped shells were just coming into supply.[1]

(c) STREAM-LINE SHELL.

The first trials with shells made with pointed heads and stream-line bases were made in the Spring of 1917.

At a conference at G.H.Q. (14 September, 1917), it was reported that stream-line shell were very inaccurate,[2] but later experiments after consultation with the French gave more favourable results. Though it appeared that no marked advantage was likely to be obtained from the stream-line shell with velocities over 2,100 ft. per second, a trial in the case of the 6-in. shell had proved very satisfactory. The 18-pdr. shell had gained an additional 1,500 yds., part of which was ascribed to the increased muzzle velocity with the improved type of gun, but part to making the contour of the head of the shell and fuse more pointed and giving a slight stream-line to the base of the shell.

The bombardment of Paris in the Spring of 1918 by a long range gun, which had a rifled shell fitted with two driving bands, led the Ministry to consider similar devices for increasing range, and trials with higher velocity guns were put in hand.

(d) LONG-BURNING TIME FUSES.

As the range of guns increased, a longer-burning time fuse than the No. 80 fuse, which burnt 22 seconds, and the No. 83, which burnt 30 seconds, became necessary.

On 28 February, 1916, G.H.Q. asked for a long-burning time fuse for use with 60-pdr. and 6-in. gun shrapnel. Though the time fuse in ordinary use must admit of use at the shortest ranges, the provision of a certain number of special slow-burning fuses, for use against enemy observation balloons at distant ranges, would add to the value of this ammunition. There was no objection to the admission of fuses which were incapable of being set for short ranges, provided they were easily distinguishable and were additional to the establishment.[3] For the 6-in. gun a fuse that could be set up to a range of 16,000 yds. should be provided, as the No. 83 fuse, which it was proposed to use, would diminish the gun's range to 12,000 yds. G.H.Q. understood that the problem of providing a time fuse which could be used up to the extreme range of the 6-in. guns would be considerably simplified, if a fuse which could not be set at anything less than, say, 5,000 yds. could be accepted, and was prepared to accept such a fuse without hesitation.[4] A similar fuse for the 9·2-in. gun was asked for on 22 March. It was not until seven months later (6 September, 1916)

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[1] Vol. X, Part III, Chap. III.

[2] *Meeting of Ordnance Committee* (7 March, 1918).

[3] C.R.4428.

[4] 121/Stores/1392 ; C.R. 4428.

that a longer-burning time fuse (No. 88) was approved by the Design Department. Its design was similar to the 83, but it used a slower-burning powder. A further design (No. 89), burning approximately 60 seconds, was produced shortly afterwards. The supply of the No. 88 was much delayed;[1] the Army Council complained on 21 January, 1917,[2] that though the design had been approved for four months, no No. 88 fuses had yet been issued and on 16 March the Commander-in-Chief asked that 50,000 long-burning time fuses should be issued. In the following month (30 April, 1917) the Ministry was informed that 20 per cent. of the total issue of 60-pdr. and 6-in. gun ammunition must be fused with long-range fuses—either the No. 88 or No. 89—but the issues of these fuses decreased in May, necessitating a reduction of 25 per cent. in the issue of 6-in. gun shrapnel to France.

These long-range fuses proved so valuable that the use of them in the field was extended and on 26 June the Commander-in-Chief asked that long-burning fuses only should be supplied for all guns from the 60-pdr. gun upwards, but on 11 July it was reported that the issue of these fuses during the last three weeks had been barely sufficient to meet weekly requirements.

When the Germans began to use a clockwork time fuse, a new direction was given to the attempt to find a satisfactory long-range time fuse. Two fired German fuses were received as samples at the end of July, 1917. These were handed to the Cambridge Scientific Instrument Company, whose representative, Mr. Mason, reconstructed the least damaged movement, so as to provide a working model of the clockwork unit. An order was then (5 September, 1917) given for 20,000 fuses of the German pattern and the representative of the firm was attached to the Ministry of Munitions to help in getting out the designs and specifications of the fuse and in supervising the beginning of manufacture and inspection. A comparison of the reconstructed fuse with an unexploded German one obtained later on showed no difference in the mechanism, though certain alterations had been made in the German fuse which made its action more regular. These later developments were copied. This mechanical fuse (which was known as the No. 200) had great advantages over the ordinary time fuse. It functioned quite accurately at the time set, and was not subject to weather conditions, which affected the rate of burning of an ordinary time fuse. There were two varieties of this fuse, one to give 60 seconds, the other 85 seconds maximum time, which differed only in minor details.

It took a long time to get the fuse past the experimental stage. A certain number were ordered in Switzerland, but gun trials of 200 of these fuses gave unsatisfactory results, failure being probably due to certain small defects in the fuses, as a trial of English-made fuses

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[1] *Meetings of Ordnance Committee* (27 July, 1916, 5 October, 1916, 9 November, 1916).

[2] C.R. 4428.

showed that all the mechanism functioned correctly. Production could not be pushed on until these trials had proved satisfactory. In order to prepare for production in bulk a new workshop had to be equipped at Luton to manufacture the clockwork mechanisms and special machinery had to be obtained from Switzerland. A further contract for mechanisms was placed at Coventry. By 10 August, 1918, both of these plants were just beginning output. It was hoped that from 300 to 500 a week would be produced in November and 2,000 a week by the following March.

A certain number of design changes—some of which were not very successful—were sanctioned during 1917 and 1918, in order to economise material, for instance, the lighter copper band, the steel centre tube in shrapnel shell, cast-iron fuse sockets, and the manufacture of the Nos. 103 and 106 fuses in cast-iron. These will be considered in another part.[1]

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[1] Vol. X, Part III, Chap. III.

APPENDIX.

APPENDIX.

(CHAPTER I.)

Maximum Weekly Requirements for Gun Ammunition under the various Programmes.

	A. July, 1915.	B. July, 1915.	C. Sept., 1915.	June, 1916.	July, 1916.	Oct., 1916.	Feb., 1917.	May, 1917.	Sept., 1917.	12 Jan., 1918.	3 May, 1918	8 Sept., 1918. G.H.Q. Programme.*
13-pdr. S. ..	18,550	16,000	—	—	9,660	—	—	—	—	—	—	13-pdr. Q.F. 5,000
„ H.E. ..	18,550	16,000	—	—	6,440	—	—	—	—	—	—	13-pdr. A.A. 35,000
15-pdr. S. ..	9,980	13,500	—	—	—	—	—	—	—	—	—	—
„ H.E. ..	29,940	3,500	—	—	—	—	—	—	—	—	—	—
18-pdr. S. ..	29,400	170,000	383,500	420,000	420,000	600,000	600,000	700,000	} 850,000	391,000	684,000 36,000 Chem.	} 850,000
„ H.E. ..	29,400	170,000	383,500	280,000	280,000	600,000	600,000	700,000 Some may be smoke		252,000	456,000 23,000 Smoke	
4·5-in. How. S	31,360	10,000	5,000	—	—	—	—	—	—	—	—	240,000
„ H.E.	125,440	75,000	219,000	248,500	248,500	314,000	314,000	342,000 Some may be Chem.	310,000	183,000 H.E. 26,000 Chem.	269,300 H.E. 38,400 Chem. 7,000 Smoke	—
5-in. How. H.E.	8,400	5,000	—	—	—	—	—	—	—	—	—	—
4·7-in. Gun S...	4,620	2,000	4,620	6,440	6,440	10,000	—	—	—	—	—	—
„ H.E.	4,620	2,000	4,620	6,440	6,440	10,000	—	—	—	—	—	—

60-pdr. S. ..	39,200	28,000	56,000	49,000	49,000	63,500	90,000	95,000	120,000	37,000	64,500	120,000
" H.E. ..	39,200	28,000	56,000	49,000	49,000	63,500		95,000 Some may be Chem.	—	36,250	94,000 1,000 Chem.	—
6-in. Gun S. ..	1,010	400	1,010	8,100	8,100	8,000	8,000	10,000	18,000	5,860	10,000	32,000
" H.E.	1,010	400	1,010	8,100	8,100	8,000		10,000	—	6,440	10,600	—
6-in. How. H.E.	57,820	56,000	126,000	204,000	204,000	275,000	225,000	330,000 and some Chem.	346,000	280,000 30,000 Chem.	281,000 58,000 Chem.	317,000
8-in. How. H.E.	6,300	13,000	45,150	80,000	80,000	80,000	65,000	68,000	64,000	50,700	35,000	47,000
9·2-in. How. H.E.	15,290	11,000	30,070	63,500	63,500	63,000	37,500	68,000	43,000	33,700	30,000	38,000
12-in. How. H.E.	1,680	1,800	4,260	5,000	5,000	5,000	—	2,500	3,100	2,325	2,000	3,500
15-in. How. H.E.	—	200	420	510	510	510	—	—	—	220	150	175
9·2-in. Gun S. ..	—	—	—	—	150	—	—	—	—	—	—	—
" H.E.	—	—	—	—	400	—	—	—	—	—	—	—
12-in. Gun S. ..	—	—	—	—	—	—	—	—	—	—	—	—
" H.E.	—	—	—	—	50	—	—	—	—	—	—	—
14-in. Gun ..	—	—	—	—	—	—	—	—	—	—	—	—

*** This programme was based only on the requirements of the Army in France, and did not include supplies for other theatres of War or for the Allies, *viz.*, 21,400 6-in. H.E., 17,000 8-in., 1,900 9·2-in. per week.**

VOLUME X

THE SUPPLY OF MUNITIONS

PART III

GUN AMMUNITION: SHELL MANUFACTURE

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CHAPTER I.

THE ORGANISATION OF SUPPLY, APRIL–DECEMBER, 1915.

I. Introductory: Supply under the War Office.[1]

(a) Direct Contracts.

During August and September, 1914, the War Office arranged for the output of the shell that would be required, according to the existing standards, by the Expeditionary Force in the Field and by the first new armies. Orders were placed with the recognised sources of supply, the Royal Laboratory at Woolwich Arsenal, and a limited number of recognised armament firms, of whom the principal were Messrs. Armstrong Whitworth, Vickers, Beardmore, Cammell Laird, Firth, Hadfield, and the Projectile Company.

During this early period the types principally ordered were shell for the guns which formed the standard equipment of the regular army —18- and 13-pdr. field guns, 4·5-in. howitzers and 60-pdr. guns. Smaller orders were also placed for ammunition for the obsolescent artillery with which the territorial army was equipped—15-pdr. field guns, 5-in. howitzers and 4·7-in. guns. The light ammunition ordered was at first entirely shrapnel, the first contracts for 18-pdr. high explosive shell being arranged in October, 1914, and for 13- and 15-pdr. H.E. later still. In the earliest orders for 4·5-in. and 60-pdr. shell, also, only 30 per cent. was to be of the H.E. type. The demand for H.E. shell, however, rapidly increased, and during the early months of 1915 the bulk of the orders were for this type.

By the end of September, 1914, a substantial output of light and medium shell had been ordered for delivery during the last two or three months of 1914 and the early part of 1915. By that time, however, the scale of expenditure, particularly of 18-pdr. ammunition, had greatly exceeded estimates, while the rapid rate at which recruiting was proceeding meant that larger and earlier deliveries must be secured, since the new armies could not take the field until a sufficient stock of ammunition had been built up. In October a Cabinet Committee was appointed to consider the whole question of munitions supply. At its first meeting, on 12 October, this committee decided on a large expansion in orders for field guns and in the ammunition for them. Additional orders were therefore placed during October and November and by the end of 1914 a total of nearly 10,000,000 shell had been ordered for guns up to 5 in.

In the meantime, steps had also been taken to obtain the ammunition required for the new heavy guns which were ordered during the autumn of 1914. The earliest orders were for shell for the 6-in. gun and howitzer, types in existence at the outbreak of war, and for the 9·2-in. howitzer,

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[1] For a full account of the events of this period, *see* Vol. I, Parts I, II, III, IV.

a type of which the first had been approved just before the war, and additional orders for which were arranged in September. Later, shell had also to be supplied for 12-in. howitzers, which were ordered in October, and for certain 8-in. howitzers which were being converted from 6-in. guns.

It was early recognised that to obtain output of shell on the scale required, the resources of firms outside the armament group would have to be mobilised. It was, however, considered at this time that the most hopeful means of securing such industrial mobilisation lay in an extensive system of sub-contracting. The armament firms who had experience of shell manufacture were capable of educating firms new to the work and organising their production, whereas the War Office, if only owing to lack of inspecting staff, could not undertake the close supervision necessary in the case of untried contractors.

Thus the bulk of the orders arranged during the first five months of the war were given to armament firms, who enlarged their own capacity by means of extensions to buildings and new plant, in addition to subletting portions of the work to other firms. The War Office was ready to assist them financially, and also to indicate possible sub-contractors by supplying lists of engineering firms who had applied to the Contract Branch for work.

At the same time, efforts were made to discover new firms capable of acting as direct contractors to the War Office. As early as the beginning of September, invitations to tender for some of the simpler natures of shell were issued to new firms, but they naturally found it difficult to secure contracts in competition with the armament firms. By the end of 1914, however, four untried firms—Messrs. J. & P. Hill, Dick Kerr, Rees Roturbo, and Babcock and Wilcox—had been given direct contracts, Messrs. Dick Kerr's order dating from the end of October and Messrs. Hill's from November.

By the end of the year it had become clear that deliveries on the orders already placed were not coming forward at the expected rate. The necessity of obtaining new plant and the increase of sub-contracting had complicated the problem of supply by introducing factors outside the control of the armament firms, who constantly found themselves obliged to revise their delivery promises owing to lack of machinery or the failure of sub-contractors. Moreover, a serious shortage of labour for engineering work was making itself felt.[1] This last point was strongly emphasised at a conference held on 21 December with representatives of the principal shell-making firms, to discuss the best means of securing a further expansion of output. The armament firms could not promise to increase their output to any large extent, and any increase was conditional on the necessary labour being available. At the same time the conference was apparently satisfied that the policy of organising the production of new firms through the armament group was the best that could have been adopted.

During the following months, however, the ever increasing requirements for shell, particularly for H.E. shell for the 18-pdr. gun, and 4·5-in. howitzer, made it imperative that new sources of supply

[1] For the steps taken to deal with this shortage, *see* Vol. I, Part II.

should be found. By this time, owing to the sub-contracting system, a certain experience of shell manufacture had been acquired by a number of engineering firms. Exhibitions of shells and fuses were held by the Board of Trade at several important engineering centres, local firms were invited to submit tenders,[1] and during the first five months of 1915, eight or nine more new firms received direct contracts.

(*b*) OVERSEAS SUPPLY.

The most remarkable expansion during the first part of 1915, however was in overseas orders, which had already been placed on a large scale. In September, 1914, a Shell Committee had been set up in Canada to obtain supplies from the Dominion, and by the end of the year large orders had been placed with this Committee, principally for 18-pdr. shrapnel shell, over 1,000,000 of which were promised in the form of rounds, complete except for the fuse. Negotiations with an American firm began a fortnight after the outbreak of war, when the Bethlehem Steel Company offered to supply guns or shell to the War Office. In October a contract for 18-pdr. shrapnel shell and 4·7-in. H.E. and shrapnel was placed, and was soon followed by an order for complete rounds of 18-pdr. By the end of the year other American firms such as the Washington Steel and Ordnance Company and Messrs. E. W. Bliss, had accepted orders.

In the early part of 1915 advantage was taken of the capacity thus created to place very large orders for delivery during the autumn and winter of 1915 and 1916. The Canadian Shell Committee early in the new year promised a large monthly output of 18-pdr. complete rounds, both shrapnel and H.E., and also undertook 4·5-in. H.E. shell, while in April a contract was concluded for 5,000,000 complete rounds, in equal parts of 18-pdr. shrapnel, 18-pdr. H.E. and 4·5-in. H.E. The American orders for 18-pdr. shrapnel and H.E. assumed even larger proportions, and considerable quantities of 12-in. H.E., 9·2-in. H.E., 8-in. H.E., 6-in. H.E., 5-in. H.E., 60-pdr. H.E., and 4·5-in. H.E. were also ordered.

(*c*) FORMATION OF CO-OPERATIVE GROUPS.

Reference has already been made to the placing of direct contracts for shell outside the armament firms, but in March, 1915, the activities of the Board of Trade in circularising firms, arranging exhibitions, etc.,[2] led to an even more important development. As early as January, 1915, engineering employers in Leicester had discussed the possibility of some system of co-operative manufacture, whereby the capacity of small firms, incapable of manufacturing a complete article, might be utilised. In March, a scheme which should embrace every process in the manufacture of certain types of shell was submitted to the War Office, and on 30 March the Leicester group received their first order from the War Office for 4·5-in. H.E. shells. This example was quickly followed by other districts, *e.g.*, Hull, Bradford, Leeds, and by the

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[1] For details of the work of the Board of Trade and the spreading of contracts, *see* Vol. I, Part III.
[2] *See* Vol. I, Part III.

end of May more than twenty Co-operative Groups had been formed under local Munitions Committees (subsequently superseded for administrative purposes by Boards of Management), and orders had been placed representing a weekly output of 9,500 4·5-in H.E. and 33,000 18-pdr. H.E. shell, although deliveries could not be expected before the autumn.[1]

In May, an alternative scheme for the establishment of a National Shell Factory was prepared by the Leeds Co-operative Group, whereby the activities of the district might be centred in one Government factory, equipped with the machinery available in the neighbourhood and administered by a local Board of Management. This example, which involved an important new departure, was rapidly followed elsewhere.[2]

(*d*) THE ARMAMENTS OUTPUT COMMITTEE.

The success of these schemes for the local organisation of shell manufacture was largely dependent upon the support of the Armaments Output Committee, which was appointed at the War Office on 31 March, 1915, and developed into a central department, under Mr. Booth and Sir Percy Girouard, for the organisation of munitions supply.[3] Arrangements were made for representatives of the Co-operative Groups to visit Woolwich Arsenal to "inspect the whole process of shell manufacture and receive whatever information and advice they needed";[4] and certain of the armament firms opened their shops in the same way. Mr. (later Sir Glynn) West, a director of Messrs. Armstrong, Whitworth, became technical adviser to the Committee, and assisted the local Committees by advising them on manufacturing processes, and supplying them with lists of machinery and details of lay-out. Foremen and operatives were also trained at the Elswick works.

The Committee also dealt with the problem of the shortage of machine tools for shell and fuse making. A machine tool branch was formed as part of Mr. Booth's organisation (27 April), and steps were taken to limit the export of machine tools of this nature, to collect particulars of the machines most urgently needed and to facilitate the manufacture of gauges. Large purchases were made in America, and a certain amount of machinery was requisitioned as it arrived in this country. The urgent question of hydraulic machinery was considered, and, after a meeting with the chief makers at the beginning of June, specifications of presses for the national factories were supplied, and it was arranged that standard plans should be issued by Messrs. Armstrong, Whitworth.

During the first twelve months of the war, shell manufacturers had no difficulty in obtaining steel for shell-making,[5] but by the spring of 1915, there were signs of a possible shortage of brass rod and copper

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[1] The formation of these Co-operative Groups is dealt with in Vol. I, Part III, and the work of the Boards of Management in Vol. II, Part II.

[2] *See* Vol. I, Part III; Vol. II, Part II.

[3] Vol. I, Part III. [4] *Ibid*, p. 65.

[5] In most cases the Armaments Output Committee undertook to supply steel at a fixed price for Board of Management schemes, *e.g.*, Hull. (HIST. REC./H./1121·21/1).

bands. The chief problems were the supply of copper tubes for the manufacture of driving bands, the shortage of brass rods, and the shortage of the very high quality spelter, which, under existing specifications, was required for brass rod, cartridge metal and Admiralty brass tubes. At the end of April, a Joint Committee of the Admiralty and War Office began to investigate the sources of supply of munition metals, and in May, a general survey of the metal position was undertaken by Sir Percy Girouard[1], and a raw materials branch was set up to deal with the supply of raw and semi-manufactured materials.

Thus by the end of May, 1915, the central organisation under Mr. Booth and Sir Percy Girouard was already dealing with the production of shell by Co-operative Groups, national factories and direct contractors, the supply of machine tools, presses and gauges, and the provision of materials needed for shell manufacture. It followed naturally that when a Ministry of Munitions was formed on 5 June, primarily to deal with the ammunition problem, this organisation became the nucleus of the new Department, and a Gun Ammunition Department (D.D.G.(A)'s division) was formed under Mr. West in the Munitions Supply Department, responsible for the supply of shell and the necessary machine tools and raw materials. The administrative work (as distinct from technical supervision) connected with the Co-operative Groups and National Shell Factories was undertaken by a separate branch (D.D.G. (B)'s division) under Mr. Booth.[2]

II. The Position in June, 1915.

At this date the shortage of gun ammunition was a very serious problem. Contractors had failed to live up to their promises on War Office orders, and out of a total of nearly 6,000,000 shell which should have been delivered by the end of May, only a third of the number had actually been received.

During the ten months between the outbreak of war and the establishment of the Ministry of Munitions, the War Office had placed orders for nearly 40,000,000 shell, but a large proportion of these were not due for delivery until the later months of 1915 or 1916. In England, the principal contractors had been disappointed by their sub-contractors, and were suffering from lack of both machinery and labour. In Canada, manufacturers had not yet overcome their initial difficulties. The largest American orders had not been placed till the spring of 1915, and deliveries on them were not due as yet; but there were considerable arrears on some of the earlier orders, owing partly to lack of familiarity with British specifications. As will be seen from the table below, which sets out the position at the end of May, the situation was extremely unsatisfactory, and particularly so in the case of some of the most important natures. Of 18-pdr. H.E., for instance, under 12 per cent. of the number expected had been delivered; there were no shell at all available for the 12-in. howitzer, a negligible quantity for the 8-in. and only 7,000 had been delivered for the 9·2-in. howitzer.

[1] Vol. I, Part III, Chap. V.

[2] *See* Vol. I, Part I, Chap. V.

DELIVERIES OF THE PRINCIPAL NATURES OF SHELL ON WAR OFFICE ORDERS.

	Total Ordered.	Position on 29 May, 1915. Due.	Delivered.	Arrears.	Total Deliveries Out-standing.
13-pdr.*H.E. Home	40,000	4,500	—	4,500	40,000
Abroad	250,000	90,000	15,394	74,606	234,606
Total	290,000	94,500	15,394	79,106	274,606
13-pdr.* S. Home	376,000	236,120	98,365	137,755	277,635
Abroad	14,000	14,000	7,500	6,500	6,500
Total	390,000	250,120	105,865	144,255	284,135
15-pdr. H.E. Home	180,000	25,000	—	25,000	180,000
15-pdr. S. Home	609,800	274,300	9,207	265,093	600,593
Abroad	300,000	100,000	62,292	37,708	237,708
Total	909,800	374,300	71,499	302,801	838,301
18-pdr.*H.E. Home	3,915,000	303,980	59,123	224,867	3,855,867
Abroad	10,191,666	445,000	27,492	417,508	10,164,174
Total	14,106,666	748,980	86,615	642,375	14,020,041
18-pdr. *S. Home	4,377,723	1,467,394	732,720	734,674	3,645,003
Abroad	11,501,666	1,729,684	669,166	1,060,518	10,832,500
Total	15,879,389	3,197,078	1,401,886	1,795,192	14,477,503
4·5-in.*H.E. Home	1,087,000	278,143	91,939	186,204	995,061
Abroad	3,141,666	95,000	—	95,000	3,141,666
Total	4,228,666	373,143	91,939	281,204	4,136,727
4·5-in. S. Home	454,540	181,567	47,120	134,447	407,420
4·7-in. H.E. Home	235,400	71,850	2,546	69,304	232,854
Abroad	120,800	30,500	—	30,500	120,800
Total	356,200	102,350	2,546	99,804	353,654
4·7-in. S. Home	24,500	9,750	—	9,750	24,500
Abroad	30,000	28,000	14,548	13,452	15,452
Total	54,500	37,750	14,548	23,202	39,952
60-pdr. H.E. Home	228,050	119,878	43,082	76,796	184,968
Abroad	360,000	—	—	—	360,000
Total	588,050	119,878	43,082	76,796	544,968
60-pdr. S. Home	187,600	120,501	67,390	53,111	120,210

* A proportion of the orders in these natures were for complete rounds.

	Total Ordered.	Position on 29 May, 1915. Due.	Delivered.	Arrears.	Total Deliveries Out-standing.
5-in. H.E. Home	400	400	—	400	400
Abroad	95,000	1,752	1,752	—	93,248
Total	95,400	2,152	1,752	400	93,648
5-in. S. Home	30,000	30,000	4,573	25,427	25,427
6-in. H.E. Home	313,400	50,200	123	50,077	313,277
Abroad	277,000	38,000	6,720	31,280	270,280
Total	590,400	88,200	6,843	81,357	583,557
6-in. S. Home	12,000	8,280	—	8,280	12,000
8-in. H.E. Home	149,300	7,200	118	7,082	149,182
Abroad	39,000	2,700	—	2,700	39,000
Total	188,300	9,900	118	9,782	188,182
9·2-in. H.E. Home	85,775	26,075	7,082	18,993	78,693
Abroad	42,000	—	—	—	42,000
Total	127,775	26,075	7,082	18,993	120,693
12-in. H.E. Home	32,000	7,500	—	7,500	32,000
Abroad	10,000	—	—	—	10,000
Total	42,000	7,500	—	7,500	42,000
Grand Total (*Shell*)	38,711,286	5,797,274	1,968,252	3,809,032	36,743,034

The problem was, however, even more serious than these figures indicate. The existing standards of equipment were overthrown at the Boulogne Conference (19 June) ; and even if all the shell ordered had been delivered at the rates promised, it would have been only about one quarter of the amount which Mr. Lloyd George set before the nation as the standard of production. In his speech in the House, on 23 June, he had stated that the Central European powers were turning out 250,000 shell per day—that is very nearly 8,000,000 shell per month—and that " the problem of victory was how to equal and to surpass that tremendous production."

Again, the new requirement for heavy shell, the value of which had been demonstrated by experience in the Field, went far beyond anything contemplated by the War Office, and deliveries on War Office orders had been even more disappointing than deliveries of light shell. The supplies which were coming in were utterly inadequate and the prospect of obtaining enough from existing sources was remote.[1]

[1] Another difficulty was the dangerous dependence on American supplies, especially for high explosive ammunition.

The evolution of the programmes for gun ammunition, which depended of course on the gun programmes, has already been treated,[1] but in order to obtain a measure of the problem which lay before the supply department a summary of the first programme printed on 7 August, 1915,[2] and of the increased programme sanctioned a month later (3 September, 1915)[3] is given in an Appendix.[4] It will be noticed that the table distinguishes between the weekly requirements of the War Office and the orders actually placed. War Office orders allowed a large margin over requirements, and this system was continued by the Ministry, which ordered about 80 per cent. of the requirement at home, and depended upon foreign contracts to produce the rest of the requirement, plus a margin as insurance against the probable failure of contractors to deliver what they had promised. Later (before 9 August), the Minister decided that 100 per cent. instead of 80 per cent. of the requirement for heavy ammunition should, if possible, be placed at home. Including existing War Office contracts, the orders placed to meet the first gun ammunition programme allowed an enormous margin, which is eloquent of the amount of reliance placed upon contractors' promises. By the time the September programme was adopted, the margin allowed had shrunk a little, the orders placed for 18-pdr. and 4·5-in. giving a 50 per cent. margin, and the orders for heavier natures giving a 33 per cent. margin.[5]

III. The First Efforts of the Ministry of Munitions to increase Supply.

(*a*) Assistance to Contractors.

As has been shown above, the supply of empty shell in June, 1915 depended upon the output of Woolwich Arsenal and of private contractors in the United Kingdom, Canada and the United States of America; but the first orders had been placed with Co-operative Groups, and the construction of National Shell Factories had started.

As a preliminary step in the expansion of output, and in order to obtain more reliable estimates of the prospective deliveries of shell and components, a schedule was sent to seventeen firms holding direct War Office contracts asking for raised estimates of anticipated production up to the end of 1915.[6]

Every effort was made to hasten production by these contractors by facilitating supplies of raw materials and components,[7] by hurrying up the makers of plant and machinery,[8] by smoothing over difficulties with inspectors and by urgent reminders and enquiries.[9] At the same time the Ministry was being overwhelmed with offers of help in munition production, offers of factories and machining capacity, offers of new

[1] Vol. X, Part II.
[2] Hist. Rec./R./1300/1.
[3] D.M.R.S. 190.
[4] Appendix I.
[5] Hist. Rec./R./1300/98 (1).
[6] *See* list drawn up on 6 July giving names of firms and natures of shell made by them. (94/Gen. Nos./148).
[7] *e.g.* D.D.G.(A.) 9462.
[8] *e.g.*, D.D.G.(A.) 2886, 7372, 8285, 9079, 9245, 9403.
[9] *e.g.*, C.R. 041; D.D.G.(A.) 967, 1567, 1636, 1691, 4939.

designs and personal services, including a variety of ambitious but impracticable plans, like that of the duchess who offered her dairy for munitions work.[1] There were also many offers from brokers who wished to get orders for shell from the United States, but, to their great chagrin, they were one and all referred to Messrs. J. P. Morgan & Co., the Government's Commercial Agent in the States.[2] Many firms and private individuals wrote to advocate the manufacture of cast iron shell,[3] and the other suggestions brought to the Department's notice included a special shell for bringing down aircraft, shells for cutting barbed wire, substitutes for thermit and a special corrosive paint.[4]

During July, August and September large additional orders for shell, fuses and cartridge cases were placed with both English and American contractors, the former being induced to extend their plant and buildings by financial help from the Ministry in the form of assisted contracts.[5] The policy of placing direct contracts with firms who had hitherto acted only as sub-contractors to the armament firms was extended, in spite of the latter's protests,[6] and a census of machinery was compiled to assist the Gun Ammunition Department in placing new orders. This census showed how many lathes suitable for light and heavy shell work were available in different districts, and, by calculating the shell capacity of these machines, a rough estimate of the amount of shell which might be produced in each locality was arrived at, an estimate which needed modification by a calculation of the number of skilled mechanics available in each area. Contracts for the No. 100 fuse were also placed in France and Switzerland, the metal being supplied from England, and special efforts were made to increase the output of gauges.[7]

(*b*) THE NATIONAL SHELL FACTORIES.

It was hoped that a steady output of the lighter natures of shell would be provided by local effort. The National Shell Factories and Co-operative Groups had accepted orders which would give the following deliveries :—

18-pdr. H.E. shell 86,000 p. w. rising to 138,000 p. w.
4·5-in. H.E. 28,900 p. w. rising to 37,500 p. w.

They had also taken small orders for 13-pdr. H.E., 18-pdr. shrapnel, and 6-in H.E. The position shortly after the establishment of the Ministry was that national factories had been set up at the following centres : Birmingham, Bradford, Bristol, Cardiff, Derby, Dundee, Ebbw Vale, Huddersfield, Keighley, Leeds, Liverpool, Nottingham, Rotherham, Swansea, and Uskside, while schemes were being considered at Grimsby and Dublin.[8] The first of these factories to begin production

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1 *e.g.*, D.D.G.(A.) 65, 701, 744, 8032, 8033, 19762 ; C.R. 043.
2 *e.g.*, D.D.G.(A.) 5163, 6893, 6900, 7006, 7101, 8275.
3 *e.g.*, D.D.G.(A.) 2419, 9266, 9681.
4 *e.g.*, D.D.G.(A.) 1754, 6488, 7470, 8256, 8952, 8957, 9136 ; C.R. 042.
5 For an account of these contracts from the financial point of view, *see* below, Chap. VI.
6 *e.g.*, D.D.G.(A.) 9525, 9759.
7 Details of this will be found in Vol. II, Part VII and Vol. VIII, Part III.
8 Vol. VIII, Part II.

was Ebbw Vale which was delivering about 120 shell a week on 31 July.[1]

In addition, Co-operative Groups for shell and gauge production had been formed at Belfast, Blackburn, Birmingham, Wakefield, Manchester, London, Leicester, Hull, Halifax, East Anglia, Derbyshire, Coventry, and other groups were projected,[2] and by the end of the year the output of National Shell Factories and Co-operative Groups amounted to over 100,000 shell a week.[3]

During July and August, the Gun Ammunition Department gave constant help to the Boards of Management, especially with regard to contract prices, supplies of raw materials and technical and inspection difficulties.[4] In many cases the local groups were affiliated to one or other of the armament firms who undertook to "mother" them and give technical help.[5]

The extension of Ministry control over the Boards of Management was rapid. On 22 July they were instructed that all their contracts must be submitted to the Ministry for approval. The high prices paid by certain Boards were criticised[6] and on 11 October all Boards were forbidden to place orders outside their districts.[7] In September the general administration of these local groups, became the function of a separate department, under Mr. (later Sir James) Stevenson as Director of Area Organisation.[8]

(*c*) The National Projectile Factories.

Close investigation showed that there was little prospect of obtaining increased deliveries of heavy shell from contractors, and this led to the decision (13 July) to set up National Projectile Factories, of which a detailed account is given elsewhere.[9] These factories were to be built at the cost of the Ministry and were to be managed on behalf of the Ministry by the armament firms, who received a commission on the cost of erection and on each shell produced. The original scheme provided for factories at Birtley (Messrs. Armstrong, Whitworth), Dudley (Messrs. Harper, Son & Bean), Cardonald & Mossend (Messrs. Beardmore), Nottingham (Messrs. Cammell Laird), Hackney Marshes (Messrs. Dick Kerr & Co.), Templeborough (Messrs. Firth), Sheffield (Messrs. Hadfield), and Lancaster (Messrs. Vickers), and it was estimated that the cost of building and equipping these factories would be between £6,000,000 and £7,000,000.[10] Later other projectile factories were arranged for at Renfrew (Messrs. Babcock & Wilcox) and Cathcart (Messrs. G. & J. Weir & Co)., while the output of the two heavy shell factories at Leeds

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1 (Printed) *Weekly Report*, Part II (31.7.15).
2 C.R. 365.
3 (Printed) *Weekly Report*, No. 24, I (8.1.16).
4 *e.g.*, D.D.G.(A.) 661, 1584, 1640, 1666, 2382.
5 Birmingham for instance was to be mothered by Messrs. Vickers (D.A.O./4/524.) Halifax, Rotherham and Sheffield by Messrs. Firth. (A.M.3/1458) *See* also D.D.G.(A.) 1644, 6955.
6 *See* Vol. II. Part II.
7 D.D.G. (A.) 7264.
8 For further details *see* Vol, II, Part II.
9 Hist. Rec./H./1300/2. They were called Projectile Factories to distinguish them from the Shell Factories.
10 Vol. VIII, Part II.

(Newlay & Hunslet) managed by the Leeds Board of Management and of the factories belonging to three assisted contractors, the Austin Motor Company (Birmingham), Messrs. Du Cros (Acton Vale) and Messrs. Rees Roturbo (Ponders End), was always included for statistical purposes with the projectile factory group. The group was designed to provide 104,500 heavy shell per week, from 4·7-in. upwards, and it was expected that production would begin at various dates between June and September, 1916.

Sites for the new factories were chosen by the armament firms, and arrangements for building them were pushed on with all possible speed.

IV. Organisation of the Gun Ammunition Department.

By August, 1915, the Gun Ammunition (or Shell Manufacture) Department had taken shape upon more or less permanent lines, and was divided into the following sections :—

A.M.1. Storage and inspection bonds, Capt. (later Major) the Hon. L. H. Cripps.
A.M.2. Raw materials, Mr. (later Sir Leonard) Llewelyn.
A.M.3. Production Branch, Mr. (later Sir Henry) Fowler.
A.M.4. Filling of gun ammunition, Col. Strange.
A.M.5. Machine tools, Mr. (later Sir Alfred) Herbert.

Four of these sections, A.M.1, A.M.2, A.M.4, and A.M.5, later achieved their independence or were transferred to other departments. Details of their work are given elsewhere,[1] but it is important to remember that they formed part of the Gun Ammunition Department during the first six months of the Ministry's existence.

(a) FILLING AND ASSEMBLING BRANCH.

The Filling and Assembling Branch was occupied with the organisation of filling factories to meet the new ammunition programme. By December, 1915, fifteen National Filling Factories had been planned and construction had started in about a dozen cases,[2] but it was decided that the filling of gun ammunition should be transferred to another department of the Ministry (D.D.G.(C.)'s division). The transfer took place on 22 December, in spite of Mr. West's protests, his chief objection being that the manufacture and filling of ammunition were so intimately linked that their severence must tend to dissipation of effort, and possibly some conflict of aim and policy. Experience confirmed him in his opposition to the divorce of filling from manufacture and in March 1917, he wrote as follows :—[3]

> "The administrator in charge of filling is concerned to secure the most economical and efficient working of his filling factories, and economy in filling may be purchased by undue expenditure in manufacture designed to supply empty components in proportions conditioned by a filling programme framed without regard

[1] Vol. VII, Parts II, III, V; Vol. X, Part V; Vol. VIII, Part III.
[2] For details, *see* Vol. X, Part V; Vol. VIII, Part II.
[3] C.S.M. 30867.

to problems of manufacture. These difficulties are inherent in a system which divorces filling from manufacture, and which tends to make filling rather than manufacture the governing factor. They are only to be overcome completely by the establishment of excess output of manufacture and the accumulation of empty stocks."

(b) Raw Materials and Machine Tool Branches.

The Raw Materials Branch of the Gun Ammunition Department placed orders for shell steel, copper bands and brass for the National Shell and Projectile Factories, and some of the direct contractors.[1] There was no shortage of shell steel, but a shortage of high speed tool steel was anticipated in October, and its export without licence was forbidden. The Machine Tool Branch (A.M.5), continued the work which had been begun before the formation of the Ministry, ordered machine tools required to equip the new factories, and exercised a general control of the machine tool trade. For the National Projectile Factories alone 10,443 machine tools were ordered, and as the capacity of British makers was exhausted, an officer was sent out to the United States to buy £1,000,000 worth of lathes. A weekly record was kept of the machine tools ordered for and delivered to national factories, assisted contractors, and to the firms who had taken big gun orders.

(c) Production Branch.

The central section of the Gun Ammunition Department was the Production Branch (A.M.3), under Mr. Henry Fowler, formerly chief mechanical engineer of the Midland Railway Company. This branch was concerned with all the details of shell manufacture and of the manufacture of shell components—of fuses, gaines, primers, friction tubes, gauges and so on. Engineers were appointed to specialise in the production of all these, to advise on manufacturing methods and the design of tools, to arrange for the carrying out of all alterations in design, and in short to be a reservoir of technical information as to the various munitions whose supply was under their charge. Special sub-sections, each under the control of a competent engineer, were set up to advise on the lay-out of machinery in factories, on electrical power supply and on the supply and erection of hydraulic presses for the manufacture of shell forgings.

Many of the contractors were new to shell and fuse work, and needed help and advice on technical questions. Books containing lists of the chief operations on shell and of the standard times for those operations, and drawings of the chief tools and jigs were sent to contractors.[2] The armament firms continued to help other contractors with technical advice, to open their works for visits, to lend machines and personnel, and to divulge the analysis of special steels and other trade secrets.[3] But they were not above criticism themselves from the technical point of view,[4] and there was some evidence of bad organisation

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[1] D.D.G.(A.) 967, 1640.
[2] 1 November, 1915. (D.D.G.(A.) 7068; C.R. 043).
[3] D.D.G.(A.) 899, 7120, 7136, 8080, 9480, 10662; C.R. 043.
[4] 12 November, 1915. (D.D.G.(A.) 7123).

and management in their shops. There were complaints that short hours were being worked owing to bad management,[1] that certain plant was so badly balanced that sometimes twenty lathes were idle for hours,[2] there was much discontent in a Scotch factory owing to an alleged shortage of work and to the employment of ex-grocers as shell inspectors,[3] and it was alleged that elsewhere "expensive machinery was rusting to ruin while the men were idle and drunken."[4] Many of these complaints came from a tainted source—discontented employees and so forth—and investigation by the Superintending Engineers showed that others were exaggerated, but at the same time there was evidence that pressure of work and the necessity of employing semi-skilled men had led to considerable disorganisation.

The section set up to deal with factory lay-outs and equipments prepared general schemes for the arrangement of plant, and gave advice on cognate questions, as well as approving individual schemes submitted for criticism. Though in view of the need of haste much more variation in the type of shell making machinery installed had to be sanctioned than was theoretically desirable, the lay-outs proposed by the armament firms for their projectile factories were compared and criticised with good effect, extravagant demands for machines being cut down in the light of general practice.[5] Special efforts had to be made to increase the output of forgings in order to supply those shell makers who had no forging capacity, and new firms who had no previous experience were induced by the Ministry to take up the work, standard drawings to guide them being prepared by the Production Department and visits to study the shell forging methods of armament firms being arranged.[6] Shell forgings were ordered in America and Canada, the first consignment from the United States arriving at the beginning of November, and the first consignment from Canada in December.[7]

A section formed to deal with the supply of electric power informed all National Shell Factories and certain armament firms by circular, on 28 August, 1915, that it was ready to help them to obtain the necessary electrical equipment.[8] For the moment the factories circularised were in no need of help. Most of the National Shell Factories were getting their supply of both light and power from the local corporations.[9] Later on, however, the supervision of the supply of power to shell factories became an important part of the Ministry's work, the tendency being ever towards a greater centralisation of supply and control.

(d) AREA ENGINEERS.

The actual work of carrying out the decisions of this central production section fell to the area engineers, who from the beginning of

[1] D.D.G.(A.) 1752.
[2] D.D.G.(A.) 9488.
[3] D.D.G.(A.) 7082.
[4] D.D.G.(A.) 6164.
[5] D.D.G.(A.) 7137; C.R. 034. Messrs. Harper, Bean & Sons were not allowed to order all the machinery they wanted. (C.R. 043).
[6] D.D.G.(A.) 1722.
[7] (Printed) *Weekly Report*, Nos. 15, 20, I. (6.11.15, 11.12.15).
[8] D.D.G.(A.) 5247.
[9] *See* replies from West of England Munitions Committee, Barnsley, Derby, Huddersfield, Uskside, Grimsby, Bradford, Keighley.

October, 1915, were under the control of the Visiting Engineer, Captain Edward Lloyd, formerly superintendent of the gun mountings department of Messrs. Armstrong, Whitworth.[1]

These area engineers (46 in number) who consisted of superintendent engineers and their assistants watched production at all munition factories. The superintendent engineers controlled the following districts: Newcastle, Manchester, Leeds, Birmingham, South Wales, West of England, East Anglia, South East Midlands, Kent, and London. Scotland and Ireland were separately organised. On 13 July Mr. (later Sir William) Weir was asked to accept the post of Supervising Engineer for the Scotch area[2] and he shortly afterwards took over the whole organisation of munitions production in Scotland with the title of Director of Munitions. Ireland developed along independent lines, two directors being ultimately appointed.

The activities of the area engineers may be summarised in the words of Mr. West's report to the Minister.

> "The primary duty of these engineers is to act as a link between Armament Buildings and the various Boards of Management and manufacturers of munitions. To the former they render all possible assistance with regard to the information required; the latter they are also able to assist by expediting the various machines, materials, etc., which are required to increase their production. The engineers are constantly being requested to urge and assist firms to increase their output, whilst they report on the suitability of firms and factories to undertake work. They urge, wherever possible, the dilution of labour and the engagement of night shifts, and push forward the general munitions work in every possible way."[3]

Reports of their work were sent in every week to the Director of Production, which, when collated, formed a general review of the progress of shell and components manufacture throughout the country. They also reported on the difficulties which hampered the placing of contracts—the delays at headquarters and the jealousies between local firms, those who had taken up war work complaining that they were losing their trade to their unpatriotic rivals who refused to undertake the manufacture of munitions. They investigated complaints of unemployment, undertook surveys of premises required for National Shell Factories, advised on questions of rent and made efforts to hasten dilatory construction.[4] A summary output progress report was sent every week to the area engineers showing them which firms in their area needed their help.[5]

The tours of inspection undertaken by Mr. West and Mr. Fowler were an important addition to this machinery. By visiting all the

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[1] D.D.G.(A.) 5514, 7029. His special duty was to investigate delays on contracts.

[2] C.R. 041.

[3] Mr. Glynn West's report to the Minister, 4 October, 1915. (C.S.M. 30867).

[4] D.D.G(A.) 1721; M.W.C.E./1461/22; D.A.O./2/243, 1010; Hist. Rec./H/1121·22/7; Hist. Rec./H/1121·22/8. Evidence of this kind of activity might be multiplied almost indefinitely.

[5] (Printed) *Weekly Report*, No. 18, I. (27.11.15).

factories in certain areas they were able to suggest the general adoption of new or improved methods which had been successfully tried in one factory. In the early days of the Ministry they were able to hasten the employment of unskilled labour in shell work by noticing cases where men were being employed on work that could be done by women.[1]

(*e*) Statistics of Progress.

For the first month of the Ministry's existence the Contracts Branch had undertaken the work of urging contractors to hasten their output, but in August the responsibility for producing guns, shells, and all munitions of war which could not easily be obtained in the quantities supplied by the War Office was transferred to the supply departments of the Ministry, the Contracts Branch being relieved of all responsibility for the punctual delivery of the stores.[2] It was therefore necessary to create some machinery in the Gun Ammunition Department to watch the progress of contracts, and when it was necessary, as it almost invariably was, to speed up output. The progress card system was therefore inaugurated about 31 July, a special section (A.M.3.J) under Mr. C. H. Stevens being formed to deal with these statistics.

The performances of the individual factories were recorded on the weekly progress cards, which had to be filled up and sent in by every firm in respect of each contract it held for shell or components, and by all the national factories. These progress reports, upon which most of the records of the statistical section of the Gun Ammunition Department were based, were found to be extraordinarily useful, though anything but popular at the factories, involving as they did an addition to the multitude of forms to be filled in and returns to be made up.

The weekly progress report gave details of the maximum deliveries of shells or components to be expected under the contract, of the number that had been delivered into bond and that had passed the preliminary examination during the week, of the total number delivered into bond to date, and the total number of accepted shells that had been issued from bond. Another card recorded the amount of raw material, of copper bands, base plates, fuse sockets, and so on in stock. Estimates of deliveries for the following week were asked for, also whether any reason could be given for the delay in reaching the promised output, whether it was due to shortage of material, difficulties with plant or inspection difficulties. Any suggestions or complaints were to be noted on the back of the card.[3]

This weekly avalanche of information flowed into the statistical section, which seized upon the essential facts and reported to the Director of Production what appeared to be the chief causes of delay. Steps were taken to remove these difficulties by transferring raw

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[1] *e.g.*, their tour of inspection on 18, 19 and 20 September, 1915, when Sheffield, Coventry, Derby and Leicester were visited. (Printed) *Weekly Report*, No. 9, I. (25.9.15).

[2] See the agreement between Mr. Geddes and Mr. Hanson, 27 August, 1915. (94/Gen. Nos./209).

[3] Monthly reports of the progress of American contracts were received from 30 September onwards. (D.D.G.(A.) 9112).

material or components from factories which had a temporary excess of either,[1] by speeding up the supply of gauges, accelerating inspection, and so on. When the reports showed that the fault lay within the factory, the local engineers were communicated with. If the progress reports from that factory continued to be unsatisfactory, Captain Lloyd visited it to investigate the causes of delay. In Sir Glynn West's words :—

> "The output progress cards were designed to aid production, and were used for the purpose of bringing the administrative resources of the Ministry to bear in every case of difficulty and delay in production with a view to removing the cause. These output progress reports became the basis of all statistical returns of output, and as experience was gained they furnished that intimate and detailed acquaintance with all our sources of manufacture, which was required for the purpose of forecasting production. Upon the success of such forecasting the economical balancing of the supplies of the various components of a complete round is largely dependent. The importance and usefulness of the system of progress returns cannot be over-rated."

Woolwich, however, was continuing a parallel activity and was issuing reminders to contractors and speeding up the execution of contracts in a way that involved a certain duplication of the supply department's efforts, and it was not until 4 December that the responsibility for watching the progress of contracts was finally transferred from the Deputy Director of Ordnance Stores, Woolwich Arsenal, to the Gun Ammunition Department.[2] The extension of the progress report system to Woolwich in April, 1916, gave very satisfactory results.[3]

V. Early Difficulties.

The months of July and August were very anxious ones. Shell deliveries rose but slowly, and in August weekly deliveries averaged less than one half of the shrapnel and less than one third of the H.E. promised. Large deliveries on the orders placed by the Ministry were due in September, but the results were most disappointing. Nearly half a million 18-pdr. shell were due during the month, but less than 20,000 were delivered.

There were many complaints as to the constant changes in specifications, and delay in the issue of drawings. The East Anglia Munitions Committee, for instance, complained that there had been five alterations in their specifications for 18-pdr. shell.[4] There were also complaints that the Woolwich inspectors required too high a standard of finish, but there was evidence that the Chief Inspector was prepared to allow a little more latitude in future. He agreed, for instance, that too fine a finish was required in the shell bore (10 September).[5]

The conflicting interests of theoretical design and of supply departments created difficulties that could only be met by compromise,

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[1] *e.g.*, in December all the armament firms were asked to lend 60-pdr. shell bands. (D.D.G.(A.) 7148).

[2] 94/Gen. Nos./322. [3] D.D.G.(A.) 15118. [4] C.R. 043. [5] D.D.G.(A.), 1567, 3684.

evidence of which appears in certain changes sanctioned by the Ordnance Board during this period—increased tolerances for screw gauges, a simpler design for shrapnel shell, the approval of malleable cast iron heads for shrapnel shell, of mild steel for shrapnel shell discs and so on.[1]

During the first months of the Ministry's existence the problem of supplying gun ammunition was further complicated by an unusual number of demands for ammunition of other that the standard types, in particular, 1-pdr. pompom ammunition for the Belgians,[2] 2·95-in. ammunition of a special double shell type with a base fuse for guns in Egypt and West Africa, and 2½-pdr. Hotchkiss gun ammunition.[3]

The production of these shells in small quantities involved disproportionate effort and sacrifice of output at a time when the demand for shell was far from satisfied, and the Ministry made several unavailing protests. These spasmodic demands for a special type, of course, persisted throughout the history of the Ministry, but on the whole the tendency was towards greater standardisation of ammunition, and the elimination of weapons requiring ammunition in such small quantities that production was uneconomical[4]. Thus, by the end of the war the British Army, which at the beginning used a number of weapons of different types (four types of field gun and three types of field howitzers being maintained in the Service) approximated much more closely to continental armies, many of the alternative weapons having been eliminated. The general policy of the Ministry in this matter was to keep a reserve of capacity at the Ordnance Factories for meeting demands for minor types of ammunition, but between July and December, 1915, the demands were so many and various that plant at the Ordnance Factories was constantly being changed over to meet a small demand; and then changed back again.[5]

In this period, too, comes the first considerable demand for anti-aircraft ammunition for the 13-pdr. and 3-in. A.A. guns,[6] and the first demand for chemical shell—10,000 cast iron 4·5-in. shell filled with S.K.[7]—which foreshadowed an immense development. The Trench Warfare Supply Department was anxious to be recognised as the department primarily responsible for the supply of chemical shell, on the ground that it had the responsibility for the supply of chemicals, which were the determining factor in design and supply. It was finally decided on 8 June, 1916, that responsibility was to be divided as follows:—

Gun Ammunition Department—Provision of empty shell.
Trench Warfare Supply Department—Provision of chemicals.
Gun Ammunition Filling Department—Supply of components, filling and assembling of shell at Woolwich.[8]

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[1] October-November, 1915 (D.D.G.(A.) 8237).
[2] O.F./S/16.
[3] C.R. 034, 035, 043; D.M.R.S. 92, 122, 207, 244; D.D.G.(A.) 10118.
[4] The War Office asked for only 1953 rounds of 2½-pdr. Hotchkiss ammunition. No drawings were in existence and it was difficult to find a contractor for such a small amount (D.M.R.S. 244; C.R. 035).
[5] C.R. 035; D.D.G.(A.) 9921.
[6] D.M.R.S. 138; D.M.R.S./W.O.R./84.
[7] 16 November, 1915 (C.R. 035, 2506).
[8] Hist. Rec./H/1640/1, p. 53.

Subsequently it was found to be undesirable for the chemical shell to be dealt with at Woolwich in the same factory as H.E. shell, and it was decided on 1 August, 1916, that the work of filling and assembling should be handed over to the Trench Warfare Supply Department as soon as their new assembling station was ready. The supply of empty shell, however, remained with the Gun Ammunition Department, in spite of the efforts of the Trench Warfare Supply Department to obtain control of it on the ground that the supply of empty shell had not come up to anticipations, and lagged behind the supply of chemicals and the capacity of the filling stations.[1]

The responsibility for the supply of 15-in. howitzer ammunition, hitherto undertaken by the Admiralty, was transferred to the Ministry in October.[2]

VI. Efforts to Meet the Increased Programme of September.

Mr. Lloyd George's new gun programme demanded an increased supply of heavy ammunition which could only be obtained in America,[3] and it was arranged that the orders should be distributed between the United States and Canada, one third, if possible, going to the latter.[4] A cable of 4 September to Messrs. J. P. Morgan & Co.[5] suggested that in addition to the continuance of all existing contracts, orders should be placed as follows :—

13-pdr. Shrapnel	12,000 per week
60-pdr. ,,	14,000 ,, ,,
60-pdr. H.E.	14,000 ,, ,,
6-in. How. H.E.	40,000 ,, ,,
8-in. ,, ,,	34,000 ,, ,,
9·2-in. ,, ,,	6,000 ,, ,,
12-in. ,, ,,	2,000 ,, ,,

The following general instruction with relation to these contracts was given to Messrs. J. P. Morgan.

> "In order to obtain the maximum output at the earliest possible time, orders for longer periods than hitherto sanctioned may be given ; one year certain or even for two years if any great advantage can be obtained in the way of early delivery. Ministry prefer a form of Contract by which they will take maximum output of a firm up to a fixed date."

Later (18 October) the Ministry decided that American orders were not to extend beyond 30 June, 1916, the period for Canada being two years.[6] Owing to the financial situation, no contracts were to be placed which would involve remittances from England in September or October.

The conference of 3 September recommended that the ammunition ordered from America should be supplied, if possible, as complete rounds, but later on, as the Explosives Supply Department were able to promise enough T.N.T., if used in the form of 80/20 amatol, for the

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[1] HIST. REC./H/1640/1, p. 57.
[2] C.R. 2451.
[3] D.M.R.S. 190.
[4] Conference on 3 September (D.M.R.S. 190).
[5] C.R. 4428.
[6] 94/S/1486.

new programme, the Ministry decided that the ammunition bought from overseas under the new programme should be unfilled, with the exception of continuation orders for complete rounds already ordered.[1] At the same time large orders were placed in Canada, *viz* :—

13-pdr. Shrapnel	5,000 per week
60-pdr. "	8,000 " "
60-pdr. H.E.	8,000 " "
6-in. How. H.E.	22,000 " "
8-in. How. "	16,000 " "

VII. Decentralisation of Inspection.

By the end of July, 1915, it was apparent that delay at Woolwich was holding up the issue of completed ammunition. The following table (26 July) gives the figures of deliveries to Woolwich and issues overseas :—

	Deliveries.	Issues to		Total Issues.
		France.	Dardanelles.	
19 June	170,000	81,000	60,000	141,000
26 June	133,000	127,000	Nil.	127,000
3 July	388,000	91,000	42,600	133,600
10 July	205,000	93,000	52,600	145,600
17 July	168,000	109,600	54,600	164,200

All empty shell had to be sent to Woolwich for inspection and filling, and the delays in getting the shell through the Arsenal were found to be due to lack of filling capacity and to congestion in the Inspection Department which was overwhelmed with work.[2] Further, shell which required rectification, a very considerable proportion in the case of some contractors, had to be sent back to the contractors' works, which involved additional expense and absorbed railway transport facilities. The defects of the system from the shell makers' point of view are set out in their letters, which denounced the intolerable delays in getting shell inspected with some vigour and asperity.[3]

The Chief Inspector, Woolwich, took the matter in hand in September, 1915, and after a series of informal conferences with Mr. West, Mr. Fowler, Major Strange and Colonel Minchin, he decided that all gun ammunition which was not required to satisfy the filling capacity of Woolwich was to be inspected at the place where it was made. This implied not only the provision of bonded store-houses for such stores as required proof, but also space for examination to be carried out and the provision of gauges and other appliances for the use of the examiners engaged in the work.

[1] 24 September (C.R. 034).

[2] 94/Gen./275. Contractors were instructed to obtain permission from the traffic manager at Woolwich before despatching large consignments—100 ton of shell and upwards.

[3] *e.g.*, D.D.G.(A.) 6922.

By 15 October bonding stores had already been provided for ammunition and components made by Munitions Boards and Co-operative Groups.[1] The Chief Inspector then issued similar instructions to all direct contractors,[2] and on 19 October, Mr. West decided that arrangements must also be made for painting the shell at the contractors' works, in shops placed as near the inspection bonds as possible. Unfortunately, a certain amount of confusion arose owing to the conflicting instructions given by different departments to the contractors with regard to the provision of bonding stores, gauges and so on.[3]

As a result of this decentralisation of inspection the Ministry proposed a reduction in the contract price of the shell, since delivery was to be taken at the works instead of at Woolwich. Some of the firms agreed upon an immediate readjustment of the contract price, in other cases the Ministry allowed time to calculate what adjustment would be equitable.[4] In many cases the Ministry undertook to provide the necessary buildings, but when the firms wished to provide permanent buildings for their own purposes which could be used temporarily for inspection, bonding and storage, the Department decided that an allowance could be made on the basis of 75 per cent. of the cost of temporary buildings such as the Ministry would provide for the purpose.[5]

Special arrangements had also to be made to meet the cost of painting shell but it was later decided that they should be painted at the filling factories.[6] Most of the shell makers were unwilling to undertake the provision of inspection gauges, and this responsibility was soon transferred to the Ministry.[7]

No action was taken at this time with regard to inspection of shells and complete rounds from America as it was understood that they were fully proved before shipment.[8] Later on, however, owing to defects, it was found necessary to reinspect American ammunition.

VIII. The Slow Progress of the National Projectile Factories.

The slow progress of the National Projectile Factories was a great disappointment to Mr. Lloyd George, who complained, on 25 September, that the information on the progress of the new National Projectile Factories contained in the Weekly Report was much too scrappy and indefinite.[9]

> " It does not give the idea that much progress has been made with the erection of these buildings, the early completion of which

[1] Departmental Conference, 16 October, 1915.

[2] Minute by Col. Stansfeld, 15 October, 1915 (94/Gen. Nos./281). Arrangements were made for using the proof ranges belonging to private firms at Silloth, Boston-on-Wash, Pembrey, Ridsdale, Eskmeals, etc., to deal with part of the material (57/Inspectors/3467).

[3] 94/Gen./281. D.D.G.(A.) 765, 2387; C.R. 034.

[4] 94/Gen. Nos./281.

[5] 7 December (94/Gen./281).

[6] 16 November (C.R. 043).

[7] 94/Gen. Nos./281.

[8] Minute by General Minchin, 27 September (C.R. 2733).

C.S.M. 30867.

is so essential to the success of our heavy-gun schemes, and thus to the success of the 1916 campaign. I should like to see reports showing what has been done and is being done for :—

(*a*) the completion of these buildings (accompanied by photographs).

(*b*) the accommodation of machinery to equip them.

(*c*) the organisation of a staff. In this case I should like to know not merely what is being done to choose managers, foremen and the directing brain generally, but also what thought has been given to the question of the labour supply in each of these works.

"There ought to be a representative of the Ministry permanently overlooking the work. His business would be to hustle. There are many first class builders in this country who would be only too glad to give their services or the services of their staff for nothing."

As a result of this criticism, a special report on the progress of the factories, accompanied by photographs, was sent to the Minister[1] and it was arranged that similar reports and photographs should be sent in weekly.

In reply to the other points, Mr. West stated that over 3,000 lathes had been ordered from America to equip the factories, delivery of which was due before April, 1916. A number of lathes had also been ordered for delivery in November and December. Nearly all the firms had chosen their managers and the directing brain generally. The sites for the National Projectile Factories had been "chosen with special reference to the labour situation so as to facilitate the supply of labour." For instance, Nottingham had been chosen as the site of Messrs. Cammell Laird's National Projectile Factory because the slump in the lace manufacturing trade had made an abundant supply of labour and ample housing accommodation available; Messrs. Beardmore's factory was situated in a district where there was a plentiful supply of female labour by which the factory was to be run almost entirely; and Messrs. Dick Kerr's factory had been placed on Hackney Marshes to draw labour from the London district. In the same way, Messrs. Rees Roturbo's factory at Ponders End would draw labour from suburban districts, and the Austin Motor Company's factory from the outlying districts of Birmingham. No difficulty was anticipated in finding labour for Templeborough, Lancaster or Dudley, or for Birtley which was to be run entirely by Belgians. The only factory where a difficulty in supplying labour was anticipated was Messrs. Hadfield's factory at Sheffield. Mr. West understood that Dr. Addison who had been considering the housing problem was making arrangements to deal with it.

In order to hasten the construction of these factories, Mr. (later Sir John) Hunter, of Sir William Arrol & Co., Ltd., was appointed as Director of Factory Construction, with full powers to push on the work (22 October, 1915). From this time onward the Directors of Factory Construction and Machine Tools sent in a joint report every week

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[1] About 30 September, 1915 (C.S.M. 30867).

showing the progress made in the erection of buildings, the supply of machinery, and the number of men at work on erection and production. The reports called attention to any special difficulties delaying the work.

IX. Lack of Balance between Shell and Components.

In September the deliveries of empty shell began to rise rapidly, but a serious shortage of certain shell components, especially of fuses, delayed the output of ammunition.[1] The situation was aggravated by the fact that a large number of 18-pdr. shrapnel and H.E. shell arrived from Canada unfused, the ammunition having been ordered as complete rounds. The 18-pdr. H.E. shell also lacked primers.[2] Deliveries of fuses on contracts already placed were most unsatisfactory.[3] A shortage of friction tubes held up the issue of the heavy shell which was urgently wanted during the first fortnight in October, and almost at the same time a serious shortage of primers and of fuse-hole plugs was discovered.[4]

Mr. Lloyd George commented on the position in strong terms on 24 September.

> "The position of components does not strike me as being very satisfactory. We first of all discover we are short of gaines, then short of primers—then we have not adequate arrangements for filling gaines. When these are set right we find we are short of detonators. Now it seems to me that our fuse filling arrangements are appalling."[5]

The explanation of the position, which was admittedly unsatisfactory, was that the Ministry had been informed that the components ordered by the War Office to meet their programme were properly balanced, and that the filling arrangements at Woolwich were adequate. It was not until the Ministry took over the Ordnance Factories (23 August)[6] that the real position, the shortage of certain components and the lack of filling facilities, became apparent. There had been very serious delays at Woolwich in erecting the extensions for filling the No. 100 fuse,[7] and the failure of the No. 80 fuse, which had been relied upon for use with 50 per cent. of the H.E. shell, had aggravated the difficulty.

In order to avoid similar difficulties in the future, large orders for friction tubes and primers were placed in France, Switzerland, and the United States,[8] but difficulties arose over the supply of material, and some of the proposed Swiss and French contracts were not proceeded with.[9] The supply of minor shell components was gradually brought up to the required level,[10] but detonation difficulties followed and produced another serious crisis before the end of the year.

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[1] (Printed) *Weekly Report* (August, September, 1915). On 25 September there were only 292,000 H.E. fuses to 592,000 H.E. shells. A considerable stock of No. 100 fuses could not be assembled owing to a shortage of detonators (C.R. 2573).

[2] (Printed) *Weekly Report*, No. 6, II. (4/9/15). [3] D.D.G.(A.) 7075, 3498.

[4] C.R. 034. [5] C.S.M. 30867. [6] M.W. 1374/10.

[7] 24 September (C.R. 034). [8] 30 September, 21 October (*Ibid*).

[9] 16 November (C.R. 035). [10] *Ibid.*

X. Fuse and Gaine Difficulties.

In view of the offensive in the autumn of 1915 the Ministry had promised the War Office to supply 100,000 rounds of H.E. ammunition of all natures per week. This promise was duly carried out, and from the beginning of October was gradually exceeded, a rate of 130,000 being reached at the end of the month.[1] In November, however, the issues began to fall rapidly, and by the middle of December amounted to only 21,000 a week. It was not until February, 1916, that issues began to recover the position that had been attained at the end of October.

This set back, which defeated all the reasonable expectations of the Ministry, was due to the condemnation by the War Office of the No. 1 gaine. The original instructions of the War Office were that a gaine must be used with practically all H.E. shells, the only exception being the comparatively small number of shell fused with the No. 17 or 44 fuses, which did not require a gaine. The bulk of the H.E. shell were fused with either the No. 100 fuse with the No. 1 gaine, or with the No. 80/44 fuse with the No. 1 gaine, this latter fuse being used with 50 per cent. of the 18-pdr. and 15-pdr. and the whole of the 13-pdr. shell.

During September, there were reports of prematures from the Front, which increased after the fighting at Loos. These reports were investigated and the War Office decided that the use of No. 80/44 fuse in conjunction with a gaine must be abandoned, as this combination had proved particularly dangerous.[2] This decision meant that nearly the whole of the H.E. shell must be fused with the No. 100 fuse, and the output of that fuse was of course insufficient to meet the whole requirement. At this point the gaine itself was found to be the cause of prematures, as it was liable to break away from the adapter.[3] Certain devices of a makeshift character were prepared, but the Ordnance Board, after full deliberation extending over two months, came to the conclusion that it was advisable to use a new type of gaine, which, being shorter and lighter than the old one, would not be liable to break away. Inasmuch, however, as the shortening decreased the amount of tetryl in the gaine to a point which was not sufficient to secure good detonation with 80/20 amatol, it was decided to introduce a fulminate detonator under the gaine, and later a trotyl exploder.[4] The design for the new gaine and detonator were finally approved on 24 November.

Supplies of the new gaine and detonator could not be obtained for six weeks as there was no plant in the country suitable for making the 10-grain detonator, but on 2 December verbal instructions were received from the War Office that no more shell with long gaines would be accepted.

Thus the issue of H.E. shell was limited by the supply of No. 44 and 17 fuses, and as these fuses could not be used for 18-pdr. H.E. shell, none of this nature could be issued during the weeks ending

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[1] D.D.G.(A.) 14518.

[2] 4 October (C.R. 2692, 2758, 2759, 2760; D.M.R.S. 160, 207, 216, 240, 241, 243, 266; D.D.G.(A.) 6931).

[3] 25 October (D.M.R.S. 160).

[4] (Printed) *Weekly Report*, No. 22, VI. (25/12/15).

11 December, 18 December, and 25 December. As the shortened gaine and the fulminate detonator became available, they were hurried to Woolwich by passenger train and motor lorry, and the position gradually improved.[1] The issue of 18-pdr. H.E. shell rose to 43,000 during the week ending 22 January (as compared with 80,000 at the end of October), and the total issue of H.E. shell to 120,000.

Sir Frederick Black, Director-General of Munitions Supply, took the view that the falling off in deliveries was in no way the fault of the Ministry, but was due to War Office decisions arrived at before the control of design and of the Ordnance Board passed to the Ministry.[2]

The Gun Ammunition Department, like other supply departments, had found the divorce of design from manufacture intolerable. As has been seen it had taken the Ordnance Board two months to decide the fuse and gaine question, and the decision of another question, important from the supply point of view—the relaxation of the specification for shell steel[3]—had also been long delayed. In order to avoid similar difficulties in the future the responsibility for designs, patterns and specifications was transferred from the Army Council to the Ministry of Munitions (29 November),[4] and, in addition, the Ministry took over the responsibility for balancing components of gun ammunition and retaining custody of such components until they were assembled as completed rounds and handed over to the Ordnance Store Department (16 December).[5] The Ordnance Board was dissolved (4 December, 1915) and reconstituted as the Ordnance Committee,[6] Mr. West becoming an associate member with the duty of watching changes in the design of gun ammunition from the manufacturing point of view.

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[1] The first supplies of the new gaine reached Woolwich during the first week in December. (Printed) *Weekly* Report, No. 19, II. (4/12/15).

[2] 6 March, 1916 (D.D.G.(A.) 14518).

[3] *See* below, p. 80. [4] M.W. 1374/12. [5] O.F./Gen./164.

[6] *Report of the President of the Ordnance Board*, 1915, p. xvii.

CHAPTER II.

FURTHER CENTRALISATION OF CONTROL AND THE GROWTH OF SHELL PRODUCTION, JANUARY, 1916—JANUARY, 1917.

I. Review of the Period.

In the period from January, 1916, to January, 1917, shell manufacture was gradually worked up to its climax, while the National Projectile and Shell Factories and the chief assisted contractors reached their full output. Programmes tended upwards, culminating in October, 1916, and were diversified by increasing demands for the new types of gun ammunition, especially for anti-aircraft shell, and for chemical, incendiary and smoke shell. In the autumn, the demand for long-range shells for the 6-in., 9·2-in., 12-in. and 14-in. guns, of 4 c.r.h. to 8 c.r.h. designs, became prominent.[1] Another important feature of the period was the adoption of the No. 106 fuse which began to be supplied in the autumn of 1916. On the other hand certain types of ammunition were dropping out. The 15-pdr. gun and the 5-in. howitzer—the old Territorial weapons—were withdrawn from service, and orders for ammunition were cancelled or reduced.[2] As home capacity was developed, it became possible to terminate American orders for the lighter natures of shell, though the size of the October programme made it impossible to reduce American heavy shell as much as had been anticipated. Canadian orders were, however, increased, and the development of Canadian shell making capacity continued throughout 1917.

The chief difficulties which the Shell Manufacture Department had to contend with in this period were the over-production of light as compared with heavy shell, which necessitated a re-allocation of manufacturing capacity[3], the delay in settling designs for chemical shell and for long range shell, a shortage of cartridge case plant, and a series of urgent demands for shell of special types, the production of which in small quantities entailed considerable manufacturing difficulties. From the administrative point of view, the period was marked by increased centralisation of control of the National Shell and Projectile Factories, two executive committees being appointed for the purpose,[4] and by the separation of the Machine Tool Branch and the Raw Materials Branch from the Gun Ammunition Department. At the same time, Mr. West became independent of the department of the Director-General of Munitions Supply, his new status being marked by a change in his official title from Deputy Director-General of Gun Ammunition (D.D.G.(A)) to Controller of Shell Manufacture (C.S.M.).

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[1] D.G.M.D./S/092; D.D.G.(A.) 10154; C.R. 038; D.M.R.S. 404/F.
[2] 10 November, 1915 (C.R. 035); 21 January, 1916 (C.R. 037; D.M.R.S. 317).
[3] *See* below, p. 35.
[4] *See* below, p. 33.

II. Arrangements for meeting Urgent and Specialised Demands.

The Shell Manufacture Department found the specialised skill and machinery at Woolwich invaluable both for meeting specially urgent demands for shell and components and for producing special types of ammunition that were required in comparatively small quantities—6-pdr. shell for the Nordenfeldt gun and for tanks, 2·75-in. shell, 3-pdr. shell for armoured cars, 1-pdr. pompom ammunition, and special types of ammunition required by the Allies. Woolwich was increasingly used to meet these urgent or unusual demands.[1] The programme to be undertaken by the Ordnance Factories was settled by conferences between Mr. West and representatives of the Chief Superintendent of Ordnance Factories,[2] but arrangements often had to be made for the factory to change over from one nature of shell to another at very short notice.

The fact that Woolwich was not included in the factories which were bound to fill up output progress reports and forward them to the statistical branch of the Shell Manufacture Department led to confusion and misunderstanding.[3] Matters came to a crisis through a serious misunderstanding as to the mark of 13-pdr. shrapnel, which Woolwich had been requested to make on 8 November, 1915. The factory proceeded to make Mark V., while the Shell Manufacture Department understood that it was making Mark IV., and from December, 1915, to March, 1916, the mistake was not discovered. Mr. West therefore questioned the adequacy of the existing machinery by which the Chief Superintendent sent returns of output to section C.M.7 in Deputy Director-General (C)'s department, and urged that Woolwich should be instructed to fill up the same output cards as were filled up by all other contractors in the trade, which showed the mark of shell which was being manufactured.[4] " I can conceive," he wrote, " only one kind of organisation which can be expected to work satisfactorily, and that is an organisation by which communications with Woolwich as to manufacture, as to the issue of extracts arising therefrom, as to meeting of trade demands from Woolwich, and as to Woolwich statistical returns, should all be centralised in one branch in my department which deals with similar questions affecting contractors throughout the country."

The change for which Mr. West pressed was introduced on 18 April, 1916. Communications with Woolwich up to the point when the extract was issued continued to go through C.M.7., but all communications on the carrying out of those extracts came to the statistical branch of the Shell Manufacture Department.[5]

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[1] *e.g.*, cartridge cases for 18/13-pdr. A.A. guns, 9·2-in. gun shell, 4·5-in. lachrymatory shell, 3-in. A.A. shell, 6-pdr. shell for tanks (D.D.G.(A.) 9962, 10317, 11384; C.R. 037, 038).

[2] 10 August, 1916 (D.D.G.(A.) 10317).

[3] 121/Stores/2842; D.D.G.A. 10317; O.F./S/16.

[4] About 12 April, 1916 (D.D.G.(A.) 15118; C.R. 039.

[5] D.D.G.(A.) 15118.

III. Delays at the National Projectile Factories.

The progress of the National Projectile Factories disappointed Mr. Lloyd George's expectations, and since the prospects of the 1916 offensive depended upon an accumulation of heavy gun ammunition, the output of this group of factories was specially important.

Replies to urgent telegrams sent at the beginning of April 1916 showed that all the factories except Renfrew and Birtley had begun operations, but that their output was very small. On 8 April, therefore, Mr. Lloyd George met representatives of the firms managing the National Projectile Factories to explain the urgent necessity of speeding up the output of heavy shell.[1] The immediate prospects of the factories were not encouraging. There were general complaints of the delay in the delivery of machine tools and in the supply of skilled labour, special complaints as to the delay in building operations, the most serious case being that of Lancaster, where the power house was not yet nearly complete, and where the output of 9·2-in. shell was not expected to begin until the first week in August ; while difficulties due to change of design had seriously affected the Rees Roturbo factory, and Nottingham. Mr. Lloyd George expressed a hope that the managing firms would make every effort to improve on their estimates as to output.

> "We are on the eve of great things," he said, "and the next few weeks and months may well decide the fate of the country. There is one clear lesson from Verdun, and that is that it is the big gun and the big projectile that tells . . . . I urge you to make a very special effort to deliver at the earliest possible moment every big shell you can . . . . The Army is clamouring for them. They want them in order to hammer the hosts of the enemy and to destroy the barbed wire and the trenches in front of them."

In the discussion that followed two main points emerged. The first was that the machinery already delivered to National Projectile Factories must be redistributed in certain cases, and the second was the labour shortage, the factories requiring about 30,000 workers male and female, skilled and unskilled, of whom only about 2,000 were then at work. There was a general agreement on the principle that as much skilled labour as possible must be drafted into the factories during the next month or two, and that dilution should not be pressed until the factories were well under way, but Mr. Lloyd George could not accept the contention that the employer should be the sole judge as to which men were indispensable, owing to the danger of munition factories being made "a city of refuge for men who were avoiding their duty."

Considerable progress was apparent by the end of the month, and one factory (Nottingham) had 41 per cent. of its full staff at work.

IV. The Campaign for more Centralised Control.

At this point the main interest shifted to an administrative problem, the need for a much closer control over the various national factories which were producing shell.

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[1] C.R. 4441.

(a) The Need for Closer Control.

The anomaly of having one group of shell factories controlled by the Area Organisation Department, while others were controlled by the Shell Manufacture Department was an obvious one, and the great variation in costs between different factories producing the same nature of shell strengthened the hand of Mr. (later Sir Hardman) Lever, the Assistant Financial Secretary, in advocating closer control by the Ministry. "This great group of factories," he wrote,[1] "offers unique opportunities for centralising buying, standardising production, collating and exchanging information and for introducing improvements so that each may profit by the experience of all." The need of this was emphasised by the striking contrasts shown upon the cost returns which were coming in from the National Shell Factories. "In some cases excellent results were obtained, in others there was obviously a serious waste of public money." During February, Dundee had produced 1,261 18-pdr. H.E. shells for every £1,000 of plant, at a cost of 8s. 9¾d., while Huddersfield, during the same month, only produced 175 18-pdr. H.E. shells per £1,000 of plant, and at the high cost of 20s. 2¼d.[2]

The National Projectile Factories, in which vast sums of public money had been invested, were on the eve of beginning output, and Mr. Lever felt that careful supervision by the Ministry would be needed since there were indications that the armament firms, by whom they were managed, were not themselves well organised.

> "Their own costs are probably unduly high, and some of them are not good buyers, as they have admitted that they pay sub-contractors for certain components prices distinctly higher than the Ministry have paid[3] ..... There is also the risk of indifference in management owing to the lessened inducement to economise as the Government is paymaster ..... Some form of central control is therefore absolutely necessary; it need not be obtrusive and would require to be exercised with great discretion so as to avoid wounding the *amour propre* of the managing firms, but with such large issues at stake it must not be open to any firm to use the word 'interference' in speaking of any supervision and guidance exercised by the Ministry in connection with the management of its own factories."

Mr. West agreed with Mr. Lever's suggestions, in so far as they concerned the National Shell Factories.[4] He thought a firmer control

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[1] 23 March, 1916 (C.R. 4441).

[2] Minute by Mr. Lever to Dr. Addison, 14 April (*Ibid*).

[3] He illustrated this by comparing the prices paid for shrapnel components as follows:—

Article.	*Armament firms.*	*Ministry contracts.*
Tin cups	2½*d.*	¾*d.*
Discs, machined	10*d.*	4½*d.*
Tubes	1*s.* 6*d.*	4⅞*d.*
Fuse sockets	2*s.* 7*d.* (brass)	1*s.* 6*d.* (steel).
Grub screws	2*d.*	1½*d.*
Lead bullets	£46 per ton	£45 per ton.
Resin	£25 per ton	£21 per ton.

[4] Minute to Sir F. Black, 25 April, 1916 (C.R. 4441).

over the Boards of Management was required, and urged that a comparison of costs of production in the National Shell Factories should be made by the Director of Production, whose engineers would be able to make due allowance for differences in factory equipment and so on, which the Finance Department was not competent to do. A system of comprehensive audit of all the activities of the Boards of Management in matters of finance, production, centralised buying, distribution of machine tools, and supply of labour appeared to be necessary. Officials representing these various branches of the Ministry should visit the factories together, enquire into all the questions comprised in their management, discuss them together on the spot, and conclude with a formal conference with the Board of Management. The visit of a body of officials familiar with the work of other factories would be the best means of carrying out the Assistant Financial Secretary's recommendations as to the co-ordination of the practical experience of working, the introduction of improvements and economies, and the introduction of friendly rivalry among the factory managers and employees. It would provide means for making supervision of returns of cost more effective, and would provide a convenient opportunity for recommendations as to the redistribution of machines and staff. From the point of view of the factories, there would be a great advantage in having the visits of different superintending officials paid simultaneously, so as to disturb the work of the factory as little as possible.

On the other hand, Mr. West did not agree with the suggestion that the National Projectile Factories should be included in this scheme. He thought they presented a different problem, and having been laid down on the most approved scientific lines, should not be included for the purpose of supervision and comparison in the same category as the National Shell Factories, which had been started with such resources as were immediately available. Further as regarded central purchase for the National Projectile Factories the central control was already organised. Shell components were purchased by the Contracts Branch, metals by the Raw Materials Branch, machine tools by the Machine Tool Branch, and small tools and miscellaneous items by a section of the Production Branch. This contention was borne out by a series of reports showing that considerable progress had already been made towards central purchasing, both in National Projectile Factories and National Shell Factories.[1]

(*b*) Central Buying of Raw Materials and Forgings.

Thus, in the case of shell steel the Ministry bought the output of the steel firms at a fixed price, and each factory was supplied from the nearest steel works.[2] Steel was not sent from a distance except in cases of special urgency. This arrangement applied to National Projectile and Shell Factories and to practically all the armament firms making land service shell. Constructional steel was bought by

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[1] Reports on centralised buying of steel and other metals, forgings, shell components, machine tools, small tools (C.R. 4441 ; 94/Gen. Nos./144).

[2] 94/S/849

the Raw Materials Branch for the Admiralty and Board of Trade, as well as for the Ministry. Prices had been fixed for the various sizes and sections, and the available supplies were allocated after consultation between the Ministry inspectors and the Admiralty overseers. In the same way, prices for the two classes of high speed steel had been fixed, and the Raw Materials Branch bought for the national factories, for armament firms, and for the Allied Governments.

Large supplies of copper had been bought in America, and were issued to the national factories and to contractors at prices fixed by the Ministry. Contracts for a supply of copper bands had been placed with various firms, and the available supplies were distributed to the various firms and factories according to their requirements. Contracts had also been placed for a supply of spelter and refined zinc. Copper and refined zinc were issued to the manufacturers of brass cartridge strip, and the strip was then issued to the factories and firms requiring it, at prices which covered the cost of material and of manufacture. In the same way, brass rod was purchased by the department and issued to the fuse makers.

The shell making industry, therefore, had the advantage of obtaining its raw materials through a department which bought on an enormous scale, while the ruinous competition between rival firms and different Government Departments had been stopped. Further, there was some kind of security that when metals were short, the distribution to the factories would be made fairly.

The arrangements for the supply of steel forgings by the Ministry had not been developed quite so early, and it was not until 28 January, 1916, that Boards of Management were informed that all contracts for forgings would in future be placed by the Ministry. In the majority of cases Boards of Management had hitherto obtained their forgings from the Ministry, but in a few cases they had been in the habit of making independent contracts. In the same way the managers of some of the National Projectile Factories had made their own arrangements for buying forgings before the system of central supply came into operation. These formed a temporary exception to the rule that all national factories which did not possess forging plants would be supplied by the Ministry with shell forgings. Central purchase was also in force for all contractors working under assisted contracts, and for practically all new direct contractors.[1] The armament firms had made their own arrangements for forgings, only coming to the Ministry for help in the case of a sudden need, but the Director of Contracts anticipated that the system of the Ministry supplying forgings would be gradually introduced for armament firms as well.

Forgings were supplied to Boards of Management at fixed prices, which, however, were rather higher than the prices actually paid by the Department.[2] In April, 1916, it was decided that forgings for continuation orders for shells from 30 June to 30 September, 1916, should be supplied at prices which bore a closer relation to the prices paid by the Ministry, which would involve considerable reductions.

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[1] Report by Mr. Hanson to Sir F. Black on central purchasing, 6 April, 1916 (C.R. 4441).

[2] *Ibid.*

(c) CENTRAL PURCHASE OF SHELL COMPONENTS.

Comparatively little progress had been made in securing that all shell components should be purchased centrally, although the question had been raised by the Contracts Branch, which on 30 November, 1915, pointed out the inconvenience of the haphazard methods in force. The practice with regard to the supply of base-plates, etc., to the National Projectile Factories was typical. Some of the firms managing factories (*e.g.*, Messrs. Hadfield and Bean and Sons), made provision for the forging of base plates in their National Projectile Factory plant ; others (Messrs. Armstrong and Firth) had made, or were making arrangements to obtain them from outside sources ; others (Messrs. Babcock and Wilcox) left the supply to the Ministry ; while others again (Messrs. Vickers, Cammell Laird, Dick Kerr, and Firth) were arranging to obtain them from their own works outside the National Projectile Factory.[1]

In addition to buying components for one or two of the National Projectile Factories, the Ministry had made certain purchases for Woolwich Arsenal and for store, in order to meet emergencies. The prices at which Boards of Management had bought components for their contractors were very high, and the Assistant Financial Secretary's contention that close control was necessary was amply justified. The copper bands for 18-pdr. shell, for instance, should have cost about 8d, but the cost at Uskside was 10d., at Ebbw Vale 11½d., and at Huddersfield 1s.[2] Experience had shown that the Ministry was able to buy shell components more cheaply than either Boards of Management or direct contractors, many of whom, as Mr. Lever pointed out, had shown themselves singularly careless in their purchases.

In order to check the payment of these excessive prices it had been decided (11 and 28 January) that the Ministry should announce the prices at which it was prepared to supply shell components, but it was not thought desirable to forbid the factories to make purchases independently.[3] It was found that most of the National Projectile Factories had made their own arrangements, and that it was too late to vary them. When, however, purchases of components had been made at a higher rate than would have been paid by the Ministry, the managing firms were told to close their contracts at the earliest possible moment, and in all cases were instructed to consult the Ministry as to the price before placing new orders.

(d) SUPPLY OF MACHINE TOOLS AND GENERAL STORES.

The Machine Tool Department contended that the system of central purchasing advocated by the Assistant Financial Secretary (23 March) already existed with regard to machine tools. The department acted as a general clearing house for machine tools, controlled the supply and distribution to all the shell factories of all the machine tools made in the country or purchased abroad.[4] In order to speed up production the National Shell Factories were frequently provided with machines

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[1] 94/National/75.
[2] 94/S/2422.
[3] Report by Mr. Judd, 11 April, 1916 (C.R. 4441).
[4] Report by Mr. Vernon, 19 April, 1916 (C.R. 4441).

originally intended for other factories. The greater part of the purchases for the National Shell Factories had already been made, and in the future machine tools would only be bought for the purpose of balancing plants, replacing worn-out or unsuitable machines, and providing for such extensions of output as might be sanctioned from time to time. All demands for machine tools from National Shell Factories had to be approved by the Area Engineer and the Machine Tool Department, usually with the advice and assistance of the Director of Area Organisation. The actual order was placed by the factory at a price approved by the Machine Tool Department, and records of the machine tools delivered to each factory were compiled. Central purchasing of small tools was also fully established. A small tool section had been set up in September, 1915, and subsequently the National Shell, Projectile, Fuse, and Filling Factories, together with engineering firms engaged on transport vehicles, aeroplanes and so on, had obtained their small tools through the branch. Some of the National Shell Factories had made their own arrangements before the small tool section was started, but, in cases of difficulty, they came to the section for help.[1]

General stores such as oil, cotton waste, cleaning materials, etc., were obtained by one National Projectile Factory—Hackney Marshes—from the Office of Works, but the Assistant Financial Secretary had decided in December, 1915, that this practice should not be extended to the other factories,[2] partly because it was considered that the National Projectile Factories had the benefit of the large purchases made by the armament firms, and partly because it was felt that it was scarcely practicable to establish an organisation at the Ministry for this purpose only, unless the Shell Factories came into line. All orders, however, for these and other purposes had to be notified to the Ministry, but no prior approval was required in the case of items not exceeding £50.[3]

The National Projectile, Shell and Filling Factories were comparatively small consumers of coal and coke, and it was therefore not worth while for them to make their purchases through the Ministry.[4] They were informed by a circular letter of 8 February, 1916,[5] that they were to make their own purchases of coal under the conditions of the Price of Coal (Limitation) Act of 1915. If they were unable to obtain supplies they were to inform the Ministry of Munitions, in order that the case might be brought to the notice of the district Coal and Coke Committee. If the factories experienced any difficulty in making contracts for coal at a price within the limitations of the Act, they were directed to refer to the Board of Trade Railway Department.

(*e*) Appointment of Co-ordinating Committees.

These reports showed that considerable progress had already been made towards central purchasing. But much still remained to be done, and there was a general agreement between the representatives

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[1] Report by Mr. J. D. Steven (C.R. 4441).
[2] 94/National/80.
[3] 94/National/142.
[4] The coal for explosive and propellant factories was bought by the Admiralty for the Ministry.
[5] A.M. 2/P. in 94/Gen. Nos./381.

of supply, finance and contracts departments that the Ministry ought to control the industry more effectively. The absence of a unified control of the national factories was thought to be responsible for the astonishing variations in costs of production, and the large amount of public money invested in assisted contracts for shell production warranted some attempt to control them more closely. So far there was general agreement. Mr. Lever and Mr. West, however, took different views as to the extent to which control should be unified. Mr. Lever's contention, as has been seen, was that the National Projectile as well as the Shell Factories should be brought under the control of one body, representing all the departments of the Ministry which were concerned, directly or indirectly, with shell manufacture; but Mr. West opposed the inclusion of the National Projectile Factories.

As a result, two committees were appointed to control shell manufacture, the D.A.O.[1] Executive Committee, which became responsible for National Shell Factories and contractors working under Boards of Management, and the National Projectile Factory Executive (N.P.F.) Committee, which controlled National Projectile Factories and assisted contracts. It was not until January, 1917, that these two committees were merged in the Shell and Components Committee. The unified control advocated by Mr. Lever in February, 1916, was therefore postponed for six months. This perpetuation of a division which was historical rather than practical was unfortunate. Though there is no evidence of friction between these two committees, which worked on parallel but independent lines, there is evidence that a single control would have produced better results.

V. The National Projectile Factory and D.A.O. Executive Committees.

The sphere of action of these two committees was defined at the outset. The National Projectile Factory Executive Committee was to deal with "all questions of vital importance or special difficulty arising in connection with National Projectile Factories."[2] Questions as to change of design, alterations to contracts and requests for additional capital expenditure came before the committee, which also dealt with the supply of skilled labour and the supply of small tools, watched the costs of production and accelerated output by eliminating "bottle necks." The committee undertook similar functions with regard to the majority of the assisted contracts, *i.e.*, all those made direct from headquarters, while the remainder, those made with Boards of Management, were supervised by the D.A.O. Executive Committee.[3]

The exact position of the Leeds factories, which had always been anomalous, was defined on 14 July.[4] All the Leeds factories were to

[1] *i.e.*, Department of Area Organisation.
[2] The committee held its first meeting 29 May (D.D.G.(A.) 17696).
[3] D.A.O. Committee Minutes, 2 June, 15 June, 1916.
[4] D.A.O. Committee Minutes, 14 July; N.P.F. Committee Minutes, 8 June (43), 14 July (99).

remain under the control of the Leeds Board of Management, but, at the same time, "the administration of the factories was to be controlled by the N.P.F. Executive Committee." This appears to be a distinction without a difference, but the situation was cleared up to some extent by the proviso that the output of 6-in. shell was to be included in the National Shell Factory returns, and that the output of larger shell was to be included, as before, in the National Projectile Factory returns. Thus the N.P.F. Committee obtained control of Newley and Hunslet, which were producing heavy shell.

Towards the end of June, the D.A.O. Committee handed over the supervision of the Ebbw Vale 60-pdr. factory to the N.P.F. Committee[1] and a little later, on 23 July, the sphere of this committee was extended to include assisted contracts for components.

The N.P.F. Committee was constituted as follows: Mr. West, Mr. Fowler, Mr. Llewelyn and Mr. Alfred Herbert were *ex-officio* members.[2] Captain O'Brien was the chairman of the committee, and Mr. Oppé represented A.M.6. The Finance, Labour, Machine Tool, Small Tools and Contracts Departments were also represented.

The D.A.O. Executive Committee, which met under the chairmanship of Mr. Stevenson, the Director of Area Organisation, consisted of representatives of the Area Organisation, Finance, Contracts, Shell Manufacture, Raw Materials, Machine Tool and Labour Departments, the Hon. H. D. McLaren being secretary.[3] Like the N.P.F. Committee it met weekly. Its function was to control the administration of the National Shell Factories and of other schemes administered by Boards of Management,[4] and it brought together representatives of all the departments of the Ministry interested in the efficient management of the factories and Co-operative Groups controlled by Boards of Management.

Some of the Boards were efficient, some of them were inefficient. Some of them had no financial interest in the contracts, others consisted almost entirely of contractors. Their manufacturing methods varied like their output and their costs of production. The aim of the committee was to put on a sound basis those factories which were neither effective nor economical, or, if there appeared no reasonable prospect of doing this, to recommend that the factories should be closed down, or that Boards of Management should be disbanded. It was not proposed that the committee should have final powers with regard to these last; its business was to make recommendations.

Its powers were therefore defined as follows:—

> "To receive reports, call for investigations and give decisions as to the effective management in shell factories and co-operative groups and to control the administration of all contracts or arrangements made by the Boards of Management. In the event

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[1] N.P.F. Committee Minutes, 23 June (68).

[2] General Office Notice, No. 85 (4 July, 1916).

[3] When other departments were concerned they were asked to send representatives.

[4] General Office Notice, No. 16 (May, 1916).

of its being considered in the interests of efficiency that certain Boards of Management should be disbanded or the personnel changed, such cases will be referred to the Minister for approval."

The committee was to judge the factories by their results. It was empowered to put pressure on Boards of Management to remove unsatisfactory managers, but was not to appoint the personnel or to take over the management.

In determining the scope of the committee's work, an interesting line of demarcation was laid down by the Assistant Financial Secretary.[1] The supervision of the committee was to be exercised only in those cases where the Ministry was financially interested in the proper carrying out of the contract, not in cases where a contractor had undertaken to supply at a fixed price. In other words, its jurisdiction was to be limited to cases in which the Ministry was interested in the manufacturing cost of the shell.

The arrangement at Glasgow was discussed and it was decided that the seven firms originally embraced in what was known as the Glasgow Shell Schemes should continue to be part of the Board of Management administration in Glasgow. Other schemes would be regarded as direct contracts with the Ministry.

VI. Over-Production of Light Shell.

In the spring of 1916, it was decided that the production of light shell must be curtailed in order to release steel for the larger natures which were urgently required for the coming offensive. This meant abandoning the 50 per cent. margin which had been adopted as a precautionary measure. Supplies of 18-pdr. H.E. and of 4·5-in. H.E. had been arranged for in excess of the gross weekly requirements (*i.e.*, the net weekly requirement plus the 50 per cent. margin), and supplies of 18-pdr. shrapnel had been ordered nearly up to the gross weekly requirement. Thus, if the 50 per cent. margin was given up there was plenty of scope for reducing the output of light shell and saving steel for the heavier natures which had proved so effective in the German attack at Verdun.[2]

It was proposed that American contracts for 18-pdr. H.E. should be discontinued in July and August, that Canadian contracts should be cut off as they fell in, say about November or December, and that the production in the United Kingdom should be reduced by 150,000 a week from 30 June. Of the firms making 18-pdr. H.E. for Boards of Management, those unable to manufacture economically would be dealt with first, and, subject to a call on their labour, firms who preferred to take up other Government work, or to a certain extent to return to ordinary commercial work would be given an opportunity of doing so. Mr. West thought that some of the shops engaged in the manufacture of 18-pdr. shell could be re-equipped for heavy shell, and that some of the American heavy shell machinery thrown on the

[1] D.A.O. Committee Minutes, 15 June. [2] A.C. 2.

market by the termination of their contracts for heavy shell might be bought for this purpose.[1]

Mr. Lloyd George decided (5 April) to cut off American and Canadian orders as suggested, but that the reduction in the home output of 18-pdr. H.E. after 30 June should only be made among the smaller firms and co-operative areas in cases where they could turn over to larger natures, or where their prices were excessive, and that the reduction of the output of 18-pdr. H.E. shell in such cases should not exceed 70,000 per week in all.[2] The 80,000 a week now contracted to be delivered by Messrs. Armstrong, Vickers and Beardmore was to be discontinued as soon as possible.

Orders for 18-pdr. shrapnel were to be dealt with in a similar way. American orders were to be cut off as they fell in—between August and November—with the exception of an order which it was proposed to place with the Bethlehem Steel Company for 750,000 complete rounds. Canadian contracts, which would otherwise come to an end in October or November, were to be continued until the end of the year, which would mean giving an order for about eight weeks' production or 2,080,000 extra shell. In this way the stock of empty shell ready for assembling would grow from 4,000,000, at which it stood in March, to about 7,000,000 in September.

Deliveries on the home orders of 4·5-in. had not yet reached a high level, and as a number of orders had been placed with small firms for small quantities, it was not anticipated that these orders would produce more than about 120,000 a week by July. The excess of supplies over net requirements would average 50,000 a week to the end of July, and the stock which stood at 1,000,000 in March would rise to 2,250,000 in September. It was decided therefore (5 April) that no new contracts for this shell should be given in the United States, but that additional orders in Canada to the number of 2,780,000 shell should be placed, and that the most uneconomical and expensive contracts in the United Kingdom should be cut down to an extent to be determined by the military opinion of the need for this shell, but not, in any event, reducing the total production from the United Kingdom and from Canada below the net requirements.

About the same time, it was decided that a six weeks' stock of all natures of empty shell should be maintained in order to keep the filling factories running smoothly. The practice of taking an actual physical count, at intervals, of the stock of empty shell, inspected and uninspected, dated from July, 1916.[3] The result of a count of the stock of shell at rest and in transit on 1 July, 1916, showed that there was a deficiency of 21,826 H.E. and of 10,541 shrapnel shell from the numbers shown on the stock lists. The number of H.E. shells in transit was 15,268 less than was estimated, but the number of shrapnel shell was 15,354 above the estimates. A more important point which emerged

[1] 23 March, 6 April, 11 April, 1916 (C.R. 4428 ; D.M.R.S. 336).

[2] At a conference between Mr. West and the Assistant Financial Secretary (about 29 April) it was decided that National Shell Factories which were not able by 30 June to manufacture shell at an economic cost, should be taken over by the Boards of Management. (Printed) *Weekly Report*, No. 39, III. (29/4/16).

[3] C.R. 038.

from these calculations was that the actual stock of empty inspected shell of all natures ready for filling was only 2·1 weeks' stock for the filling factories at their then rate of filling, instead of the six weeks' stock which it had been agreed should be kept.[1]

VII. Re-allocation of Manufacturing Capacity.

The decision to decrease the amount of light shell manufactured and increase the amount of heavy shell entailed a re-allocation of manufacturing capacity, which was the chief pre-occupation of the Shell Manufacture Department from April to September, 1916, and this re-allocation was only just completed when the new programme of October, 1916, necessitated another re-survey and re-allocation.

In making arrangements for an increased supply of shell of the heavier natures, the department decided that no more plant was to be obtained for starting shops on new sizes of shell.[2] There was not enough available labour in the country to run the existing machinery to its fullest extent, and the mere multiplication of machine tools would mean the absorption of still more highly skilled labour by the machine tool makers. It was to the public interest that all the factories which were producing shell economically should be supplied with labour sufficient to run their machines night and day to their fullest capacity, and continuous production by the larger factories would be equivalent to the output of dozens of small factories.

The question of finding employment for the factories hitherto making 18-pdr. shell presented great difficulties, as their plant and organisation was not usually suitable for the manufacture of heavy shell. There was a rule that 80 per cent. of the requirements of the Trench Warfare Supply Department had to be placed through Boards of Managements, although there was a tendency to evade this obligation, and the department was asked to obtain a certain proportion of its requirements from firms who had up to then made 18-pdr. shell, provided they were capable of doing the work. Its reply was, however, to the effect that it would be difficult to place requirements for Stokes shell at the disposal of the committee for allocation among firms contracting under Boards of Management, unless the demand for Stokes shell was increased.[3] The shell shortage aggravated the position; from the beginning of June only 1,000 tons of steel per week would be available for 18-pdr. H.E. manufacture, and a further reduction of output became necessary. It was decided that all the National Shell Factories, the four direct contractors, and as many of the 400 firms manufacturing for Boards of Management as possible, should be stopped manufacturing this class of shell. Where it was not possible to turn over the last named class to other requirements, their output was to be reduced to

[1] 14 July, 1916 (C.R. 4429).
[2] D.A.O. Committee Minutes, 19 May, 25 May, 1916.
[3] D.A.O. Committee Minutes, 29 May, 1916.

one half, in consideration of their being allowed to spread it out over a longer period.

It was possible to employ a certain number of these factories on the nose-bushes required for 60-pdr. and 6-in. shell. The allocation of the available orders was a difficult problem which was met by the appointment on 22 June of a standing committee, known as the Allocation Committee, to discuss the allotment of requirements between co-operative Boards of Management, National Shell Factories, and direct contractors.[1] This committee did useful work in smoothing over the difficulties of the transition period, and in June, contracts for 6-in. and 60-pdr. shell noses were given to contractors, to tide them over the period before the forgings for 18-pdr. shrapnel, which were required at the rate of 200,000 per week from September onwards, became available.[2] No new machining plant was to be installed; the shell-makers were to be supplied with rough-turned and centred forgings, which would be available from September onwards and the Ministry would supply all components. The Boards of Management were not prepared to supply more than 60,000 18-pdr. shrapnel a week on this basis, as their contractors did not approve of the components supplied by the Ministry.[3]

On 28 July, the Allocation Committee decided that 18-pdr. shrapnel contracts should not be given for a less quantity than 1,000 a week from any one contractor, unless arrangements could be made for assembling at a National Shell Factory. Other requirements for smaller quantities of different kinds of ammunition—for 12,000 60-pdr. H.E. shell, for 70,000 6-pdr. cast steel shell, for 13-pdr. H.E., for 18-pdr. N.T. shell, for 3·7-in. mountain howitzer, for 3-in. 20 cwt (without N.T.), for 4·7-in. H.E. shell, for 2-pdr. ammunition and for 6-in. incendiary shell—were considered by the Allocation Committee at subsequent meetings.

VIII. The Effect of the Programme of October, 1916.

Scarcely had the factories which had been taken off the production of 18-pdr. shell settled down to their new work before an increased demand for light shell arose as a result of the new gun ammunition programme of October, 1916. The evolution of this programme, which far surpassed all previous demands for gun ammunition, has been considered elsewhere.[4] It remains to outline the steps taken by the Shell Manufacture Department to provide the shell. After full deliberation, the Advisory Committee recommended that the following manufacturing programme should be adopted, and the programme was endorsed by the Minister.[5]

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[1] The committee consisted of Mr. Stevenson, Mr. Fowler, Mr. Maclean, Mr. Stevens (A.M. 7), Mr. Jenkins, Mr. Bertram (Contracts Branch), and Mr. McLaren.

[2] D.A.O. Executive Committee Minutes, 16 June; Allocation Committee Minutes, 30 June.

[3] *See* below, p. 90. [4] Vol. X, Part II. [5] A.C.2.

ALLOCATION OF PRODUCTION OF SHELL BODIES TO MEET 1917 PROGRAMME.

Class of Shell.	Requirements per week.	To be obtained from: Home Capacity.	To be obtained from: Canadian Capacity.	Notes.
18-pdr. H.E. ..	600,000	600,000(*a*)	(*a*)	(*a*) If home capacity cannot be raised to 600,000 per week, Canada to be asked to supply 50,000. If home capacity still insufficient new National Shell Factory to be established in United Kingdom.
18-pdr. S.	600,000	300,000	300,000(*b*) (Cost, £300,000 p.w.)	(*b*) Canadian supply to be in complete rounds. If home capacity not sufficient Canada to be asked to increase to 350,000 rounds per week.
4·5-in. H.E. ..	314,000	154,000	160,000 (Cost, £252,000 p.w.)	
4·7-in. H.E. ..	10,000	10,000	—	
4·7-in. S.	10,000	10,000	—	
60-pdr. H.E. ..	63,500	48,500(*c*)	5,0001 (Cost, £36,000 p.w.)	(*c*) Home capacity estimated at 61,000. Surplus could be used to meet shortage of capacity for 6-in. howitzer requirements.
60-pdr. S.	63,500	63,500(*d*)	—	(*d*) Home capacity estimated at 78,000. Surplus could be used to meet shortage of capacity for 6-in. gun shrapnel requirements.
6-in. Howitzer ..	295,000	141,000(*e*) rising to 145,000	100,000 (Cost, £310,000 p.w.)	(*e*) Deficiency to be made up by transferring 60-pdr. shrapnel capacity, failing reduction of requirement by War Office to 245,000 rounds.
6-in. Gun H.E. ..	8,000	8,000	—	
6-in. Gun S... ..	8,000	5,750(*f*)	—	(*f*) Deficiency made up by transferring 60-pdr. shrapnel.
8-in. How. H.E. ..	80,000	51,000 rising to 60,000 after June 1917.	20,000 (Cost, £150,000 p.w.)	There were orders placed in U.S.A. for delivery up to end of March, 1917, of approximately 200,000 8-in. and 200,000 9·2-in. shell per month, which it was estimated would keep up supply whilst home and Canadian capacity was brought up to these figures.
9·2-in. How. H.E. ..	63,000	33,000 rising to 43,000 after June, 1917.	20,000 (Cost, £230,000 p.w.)	
12-in. How. H.E. ..	5,000	5,000	—	

One of the chief features of the programme was the heavy demand for 18-pdr. shrapnel. The 18-pdr. H.E. issued during the winter of 1915–1916 had been a disappointment. The Army found that it did not do what was expected of it, and, in the spring of 1916, General Headquarters had requested that 70 per cent. of the supply of 18-pdr. shell should be shrapnel. It was quite impossible for the Ministry to undertake to supply this amount, mainly owing to the difficulty of increasing the output of time-fuses, and a compromise on a 60 per cent. basis was accepted.

The Army would have liked to have had 70 per cent. of the new requirement of 1,200,000 a week in shrapnel, but the Ministry was unable to supply shrapnel at this rate (about 900,000 a week), and at the urgent request of the Department, G.H.Q. agreed to reduce their demand for shrapnel to 50 per cent. of the total—600,000 a week.[1] As there were between ten and fifteen million 18-pdr. H.E. shells in hand, the Ministry urged G.H.Q. to make the non-offensive part of the line use high explosive shell in order to educate the troops in its use. The supply departments, however, were informed that the soldiers were accepting this smaller proportion of shrapnel at the urgent request of the Ministry, and that if it were possible to increase the proportion it ought to be done.

The outlook as to the supply of shrapnel from home sources was not very encouraging. The deliveries in October averaged 165,000 a week, and the estimates of the possible development of output did not rise above 250,000 to 300,000 a week.[2] The Advisory Committee, therefore, accepted the position that 50 per cent. of the supplies of 18-pdr. shrapnel must be obtained from overseas.

After stating that they considered that there was no serious outstanding limiting factor which would prevent the War Office programme for 18-pdr. shell being met early in the second half of 1917, the Advisory Committee, on 18 October, made the following recommendations :—

(i) (*a*) "That the home production of 18-pdr. H.E. shells be brought up to 600,000 per week.

(*b*) "That immediate instructions be given to the Steel Department to increase the allocation of steel from 750 to 2,000 tons a week in order that operations may be commenced, this immediate increase being made from British supply at the expense of larger natures of shell say 9·2-in. and 8-in.

(*c*) "That D.A.O. be at once instructed to find out from the Boards of Management the possible maximum output that can be obtained from the sources under his administration.

(*d*) "That C.S.M. in conjunction with the Contracts Branch be also instructed to ascertain the quantity obtainable from direct contractors.

(*e*) "That if the sources of supply mentioned in (*c*) and (*d*), prove insufficient, Canada be asked to manufacture 50,000 H.E. shells per week.

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[1] D.M.R.S. 440 ; A.C.2, 147.

[2] A.C.2.

(*f*) "That whatever balance may then be necessary should be procured by the establishment of a National Shell Factory or National Shell Factories in this country.

(ii) "That 300,000 rounds per week of 18-pdr. shrapnel be obtained in this country.

(iii) "That an order be given to Canada for 300,000 complete rounds of shrapnel per week.

(iv) "That in the event of it not being possible to produce 300,000 rounds of shrapnel per week in this country, Canada be asked to supply up to 350,000 complete rounds per week.

(v) "That the present order with the Bethlehem Steel Company, U.S.A. for 70,000 complete rounds of shrapnel per week be continued for January, February and March, 1917, provided the price is approximately $12."

The committee stated that the increase in expenditure would amount to about £1,100,000 per week. Of this amount £350,000 would be spent in Canada and £750,000 in Great Britain. This was exclusive of any possible expenditure on additional plant and buildings in this country. Should the Bethlehem order be placed there would be an additional expenditure in the United States of £2,430,000. These recommendations were accepted by the Minister, and carried out by the Shell Manufacture Department in conjunction with the Department of Area Organisation.[1] The D.A.O. Committee decided (20 October) that there would be no difficulty in immediately releasing all the National Shell Factories, if necessary, from the manufacture of 60-pdr. and 6-in. shell noses, and in releasing the Board of Management contractors gradually, in order to turn them back to 18-pdr. H.E. shell.

The effect of all these changes on the contractors may be illustrated by the experience of the firms contracting under the East Anglian Board of Management. In June, 1916, these firms had undertaken contracts for 13-pdr. shrapnel in lieu of completing the balance of their 18-pdr. H.E. contracts. They had been unable to obtain 13-pdr. forgings and had not started work on 13-pdr. shell in November, when it became necessary to ask them to go back to 18-pdr. shell. With a view to estimating the financial compensation payable to these firms, the D.A.O. Committee asked for estimates as to the cost incurred by them in altering their plant, and details of the balance of 18-pdr. contracts unexecuted on 30 June. On December 1, it was reported that negotiations for the cancellation of their 13-pdr. contracts had been completed on the following terms. The Ministry was to take over the components ordered in connection with this contract at the standard price, and the Board agreed to accept a sum of approximately £5,500 (representing the actual expenses of the firms for converting their machinery to 13-pdr. manufacture) in lieu of the 6d. per shell (which they could legally claim under the break-clause) in respect of the contract number of shell undelivered—a claim which would have amounted to about £10,000.

[1] *See* above, p. 38

The October gun ammunition programme brought also an increased demand for heavy ammunition, which entailed great efforts on the part of the Shell Manufacture Department. It was decided that the weekly output from the National Projectile Factory group must be raised from 150,000 to 190,000, a revised maximum being assigned to the factories producing 60-pdr., 6-in., 8-in. and 9·2-in. shell. The October programme, however, showed a reduction in the requirement for 12-in. and 15-in. ammunition, and there was therefore spare capacity which could be allocated to other natures of shell.[1]

In addition, a new assisted contract was placed with the Austin Motor Company for the production of 8-in. shell at the rate of 5,000 increasing to 12,000, a week, delivery to begin in January, 1917.[2] An expenditure of £557,901 10s. 6d. for plant, etc., was approved on 9 January, 1917. The contract was on a co-operative basis, the maximum price of the shell being fixed at £6 15s., and there were the usual provisions for the firm to earn a bonus by economical production. Orders were also placed in Canada for 20,000 8-in. shell per week, and in the United States for about 200,000 shells for delivery before the end of March, 1917, which would keep up supply while home and Canadian capacity was being worked up to meet a programme requirement of 80,000 a week. It was anticipated that the home output might be increased to 51,000 a week during the first six months of 1917, rising later to 60,000 per week, while the balance must come from abroad.

Similar steps were necessary in the case of 9·2-in. shell in order to meet the October, 1916, programme, which required 63,000 rounds of 9·2-in. ammunition a week. It was estimated that the output in the United Kingdom, which averaged 21,646 a week in December, could be increased to 33,000 by June, 1917, and to 43,000 after June, 1917. To make up the balance, 20,000 shells a week were ordered from Canada, and 200,000 shell in the United States for delivery before March, 1917.

It was more difficult to meet the huge demand for 6-in. ammunition, which was one of the chief features of the new programme. The weekly demand was for 295,000 rounds per week, which amounted to one quarter of the total weight of shell in the whole programme. The output of 6-in. shell from home sources averaged 90,860 a week in December, and the maximum output from the existing capacity was estimated at 141,000 a week, rising to 145,000 a week in March, 1917.[3] Special efforts, therefore, had to be made to meet the balance of the requirement. Orders were placed in Canada for a weekly production of 100,000 shell, which meant doubling the existing output. The National Projectile Factories making 6-in. shell were instructed to work up their production as rapidly as possible, and in January the estimates of their output were raised from 56,000 a week to 61,500 a week.

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[1] D.M.R.S. 440; A.C.2; Shell and Components Committee Minutes, 29 January (331); A.M. 6/Renfrew P/4; 94/S/4184.

[2] 94/S/4184.

[3] 23 October (A.C.2).

Fortunately the home capacity for the production of 60-pdr. H.E. and shrapnel shell was more than sufficient to meet the requirement for 63,000 a week of each type, and it was decided that part of this capacity should be converted to the manufacture of 6-in. gun and howitzer shell. Contractors were to be repaid their expenditure on altering machines and equipment, and the allocation of 60-pdr. steel was to be reduced to 20 per cent. below the contract rate.[1]

[1] Shell and Components Committee Minutes, 22 January, 1917 (13 and 28), 5 February (41), 12 February (57).

CHAPTER III.

THE CLIMAX OF SHELL PRODUCTION.

I. Introductory : Review of the Period.

By the beginning of 1917, shell production had been worked up to a very high level, a weekly average of just under two million shell, about half of which came from abroad, being reached in December, 1916. The huge programme launched in October, 1916, as a result of the battles of the Somme was in bearing, and there was ample evidence that the productivity of the national factories, though far surpassing original estimates, had not yet reached its limits. But this immense production was not destined to continue without a check. The provision of shell had far outrun the provision of guns, and in March the shell programme was reduced, the machining capacity of some of the great factories set up for shell-making being diverted to gun-repair. The reduced programme cut down the demand for heavy shell, while leaving that for the lighter shell, of which such vast quantities were consumed by the barrage system, untouched, and several of the National Projectile Factories were therefore turned over—partly or completely—to 18-pdr. and 4·5-in. shell. While these changes were in progress the effect of the unrestricted submarine campaign became felt, and the consequent demands for steel for new tonnage and for guns for merchant ships pushed the demand for steel for shell manufacture—urgent as it was—into the second place. As will be seen below, there was no longer enough steel to keep the great shell factories going at their full capacity, but, fortunately, their surplus energy could be turned into other channels. One of the National Projectile Factories undertook aeroplane work, another became a gun factory, while the shell-making plant of many private firms was converted to other war uses.

But the period of the most drastic restriction of shell output did not last long. By the end of May, the outlook had improved ; the programme adopted in July showed a considerable increase on the current programme, though it was still below the level of the original 1917 programme, and in December, 1917, the home production of shell reached its maximum of about 1½ million per week.

The following table shows the growth in the weekly output of shell from all sources at home and abroad :—

Date.	Output of shells from all sources (weekly).	Steel used per week in tons.
June 1915	150,000	
June 1916	1,896,670	36,037
June 1917	1,607,382	47,570[1]
Feb. 1918	1,587,000	53,000
Sept. 1918	2,027,000	66,000

[1] The greater tonnage of steel appearing against lower output is accounted for by the higher production of the larger natures of shell.

At the same time new types of shell were coming into supply, the most important of which were long range shells for various natures, and cast iron shell for chemicals. The period, therefore, is in some ways a specially interesting one, though owing to the rapid changes of programme, it was a difficult and anxious one for the Shell Manufacture Department.

The climax of shell production at home having been reached in December, 1917, the chief interest in 1918 lay, not in stimulating output, but in stimulating economy of money and of man-power, of machinery and materials. Economy of material was of vital importance, the first and last word in the shell situation being the supply of steel. Copper and brass were also a source of anxiety, and substitutes were investigated and in some cases introduced. Economy in its narrower sense was promoted by a series of investigations into costs and efficiency, the most important being the enquiry into the financial results of a year's working of the National Projectile and Shell Factories. The policy of setting up great national factories was endorsed by this investigation even on the narrowest financial grounds, while their value in the broader sense was proved by the comparative ease with which they were turned over from heavy to light shell, and from shell-making to other munition work.

The many variations of demand during 1917 and 1918 entailed constant interference with the output of firms and factories. For the sake of convenience, and in order to explain the chief fluctuations, the manufacturing programmes for shell bodies as approved by the Minister in October, 1916, on 7 March, 1917, and the reduced programme sanctioned on 13 April owing to submarine activities, are given in an Appendix,[1] together with the manufacturing programmes for 1918 as settled on 24 May[2] and revised on 10 July, 1917, 3 May, 1918, and 23 September, 1918.

II. Administrative Changes: the Shell and Components Executive Committee.

The work of the N.P.F. and D.A.O. Executive Committees had been an unqualified success, mainly owing to the fact that they brought together representatives of all the departments concerned in the business of shell manufacture, and that their decisions were therefore endorsed by these departments. The Director of Area Organisation, therefore, proposed on 11 December, 1916, that this successful policy should be pushed to its logical conclusion, that the two committees should be united so that one executive should control the whole shell and components situation.[3] The fact that a new gun ammunition programme with all its attendant negotiations as to forgings, shells, fuses, and components was being embarked upon made a unified organisation of the technical, organising, finance and contract arrangements more than ever desirable. The Controller of Shell Manufacture agreed: his suggestion that the direct contractors should also be included in the sphere of the proposed joint committee was adopted, and a further

[1] Appendix II. [2] A.C. 71. [3] D.A.O./Misc./418.

suggestion, that the new committee should also take over the Swiss and French contracts, was accepted with a slight modification. The Minister decided that the miscellaneous work on Swiss and French contracts, outside the gun ammunition work, should continue to be administered by Deputy Director-General (B.)'s department.[1]

The new committee, which was known as the Shell and Components Manufacture Executive Committee, was given control of " the allocation and administration of all Shell and Components, with the exception of the administration of orders allocated to Canada and the United States."[2] It became responsible, therefore, for the manufacture under Boards of Management formerly controlled by the D.A.O. Executive Committee, for the National Projectile Factories, formerly administered by the N.P.F. Committee, for the manufacture under contracts placed direct with British firms by the Ministry, and for the manufacture under contracts placed in France and Switzerland, formerly controlled by Deputy Director-General (B.)'s department.

The composition of the Shell and Components Manufacture Committee was as follows:—Sir Glynn West (Chairman), Captain Dewar, Mr. P. Hanson, Mr. J. B. MacLean, Hon. H. D. McLaren, Mr. John Mann, Mr. C. H. Stevens, Mr. J. Stevenson. Mr. McLaren acted as secretary to the committee with Mr. Macnaughton as assistant secretary. The first meeting was held on 15 January, 1917, and the last meeting on 10 September, when the reorganisation of the Ministry and the creation of the Munitions Council made further meetings of this committee unnecessary.

During the eight months in which it controlled shell manufacture the Shell and Components Committee continued the work of the two committees it had superseded, but its wider scope brought within its orbit the whole field of shell manufacture. The great armament firms and the 4,000 other contractors were included as well as the national factories, shell contracts placed in Canada and the United States alone being excepted. To quote the minutes of its first meeting, the committee was

> " formed in order to simplify the present organisation dealing with the placing of contracts and the production of shell and components. One of its main functions will be to co-ordinate the work of the different departments and sections concerned and to provide machinery for the giving of immediate decisions on urgent questions that arise from time to time and affect one or more departments."[3]

Certain statistics as to the available supplies of steel, the allocation of steel for shell production, and the costs of shell production in the various national factories were presented at regular intervals to the committee, which was therefore in a position to meet demand as far as possible out of the available supplies of steel, and to arrange for the numerous " change overs " called for by varying requirements or modifications of design, with as little inconvenience to manufacturers as possible. During the eight months of its existence this effort to

[1] D.A.O./Misc./418. [2] General Office Notice, No. 85 (5 January, 1917).
[3] Shell and Components Committee Minutes, 15 January.

meet requirements economically was the most vital part of the committee's work. Its work in regulating prices and comparing costs of production increased rather than diminished as time went on. Cost returns became more valuable as the number of the factories from which they were obtained increased, and when checked by the theoretical "costings" prepared in the Finance Department, gave the Ministry a standard cost by which to judge existing and guide future contracts. On the other hand the control of the expenditure of the National Projectile and Shell Factories that had been such an important part of the activities of its predecessors had become more and more a matter of routine, and, as will be seen below,[1] there were few attempts to evade the control of the committee and these were not of the first importance. In the same way the elaborate system of progress reports had reduced the spasmodic "hustling" of early days to an exact science. Estimates of deliveries were now a matter of calculation based on previous records rather than optimistic guess-work, and when there were no labour troubles, shell manufacture ran with the precision of a vast machine. The chief work of the Ministry therefore throughout 1917 or 1918 was to feed this vast machine with steel and forgings, base plates and copper bands, and to adapt its output as rapidly and completely as possible to the varying demands of the War Office.

On 1 March, Sir Glynn West was appointed to organise additional capacity for gun repair, Mr. C. H. Stevens being appointed Acting Controller of Shell Manufacture. A re-organisation of the Shell Manufacture Department followed.[2] Section A.M. 6 disappeared as a separate branch, its costing section was transferred to the department of the Assistant Financial Secretary, and its other duties were divided between A.M. 3 and A.M. 7. The administration of the National Projectile Factories was transferred to the Production Branch (A.M. 3), which was already responsible for shell production outside the National Projectile Factory group. The logical completeness of its functions was, however, marred to some extent by the fact that its control over the National Shell Factories was limited to questions of labour and welfare, the Director of Area Organisation being responsible for other questions of administration. Another function hitherto undertaken by A.M. 6—the investigation of works management and machine shop efficiency by supervisory engineers—was also transferred to A.M. 3, while its responsibility for the supply of materials and components to National Projectile Factories and assisted contractors and for maintaining statistics of these stocks of materials was transferred to A.M. 7, which henceforward centralised the work of keeping statistics and output progress returns and returns of the distribution of steel, of the manufacture and distribution of forgings, throughout the whole field of shell manufacture. This reorganisation, which economised

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[1] *See* below, p. 92.

[2] At this date the department was divided into the following sections:—A.M.1, Storage and inspection bonds; A.M.8, Supply of gauges; A.M.3, Production of shell and components; A.M.7, Output progress statistics; A.M.6, Administration of National Projectile Factories and Efficiency; Electric Power Supply Branch.

staff and money, while allowing a more convenient distribution of duties, was approved on 29 March, 1917, and the organisation remained substantially unchanged throughout 1917 and 1918, save that when in 1918 the responsibility for the supply of certain trench warfare stores was transferred to this department, new sections (A.M. 14 and A.M. 15) were created.[1]

On 30 May, Sir Glynn West took over the responsibility for the production as well as the repair of guns, with the title of Director-General of Shells and Guns, Mr. Stevens becoming Controller of Shell Manufacture. When the Ministry was reorganised by Mr. Churchill, Sir Glynn West became a Member of Council for Group G., which included guns, and the Shell Manufacture Department was transferred to Group P., under Sir James Stevenson. On Sir Glynn West's retirement (17 January, 1918) Groups G. and P. were amalgamated, and became the Ordnance Group with Sir James Stevenson as Member of Council, Mr. Stevens becoming Controller of Gun Ammunition Manufacture.

III. The Effect of the Reduced Programme of February, 1917.

(*a*) Recommendations of the Advisory Committee.

The effect of the reduced demand for finished gun ammunition on the shell manufacturing programme was considered in February by the Advisory Committee, which made recommendations as to the extent to which reductions should be distributed between the United Kingdom and Canada, the best way of reducing output without sacrificing the capacity to enlarge output again later, the use to be made of labour and manufacturing capacity set free by the reduction, the effect of the reduction on the output of raw materials, the steps which might be taken to allot the materials thus set free to other purposes, and the extent to which the reduced programme would affect extensions to factories then in progress (2 March, 1917).[2]

The Advisory Committee reported (1) that there was a considerable over-production of 60-pdr., 8-in., 9·2-in. and 12-in. howitzer ammunition; (2) that there was an under-production of 18-pdr. and 4·5-in. shell; and (3) that the production of 6-in. gun and howitzer ammunition was approximately correct. In order to meet the situation, they therefore recommended that more steel should be allocated to 18-pdr. and 4·5-in. shell by changing over steel then used for the heavier natures, and that the excess capacity of 60-pdr. should, if necessary, be changed over to the production of 4·5-in. shell.

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[1] At the time of the Armistice, the department consisted of the following branches :—A.M.3/A., Production of shell; A.M.3/B., Fuses, gaines, cartridge cases; A.M.3/C., Administration of National Projectile Factories and direct contracts; A.M.4, Layout and equipment of assisted contracts; A.M.5, Production of shell forgings; A.M.7, Distribution of shell forgings and components; A.M.9, Requirements, statistics and records; A.M.14, Grenades and miscellaneous trench warfare stores; A.M.15, Aerial bombs. A.M.1, A.M.8, and the Electric Power Supply Branch had become independent departments.

[2] A.C. 71.

Even this reduced programme involved the transport of 54,633 tons of gun ammunition to France every week. In addition, it was calculated that there would be about 4,000 tons of trench warfare munitions, small arms and railway material; and in view of the fact that it had been reported that the maximum amount of cross-channel tonnage available was 56,000 tons a week, the Advisory Committee asked the Minister to draw the attention of the War Office to the fact that the reduced gun ammunition programme would require about 55,000 tons of transport facilities weekly.

The Advisory Committee reached an agreement on the manufacturing programme for light and medium shell with little difficulty. The importance of speeding up the manufacture of 18-pdr. H.E. in the United Kingdom was fully realised. The output in March was only 100,000 a week, and, in order to average the 420,000 per week required from the United Kingdom, it would be essential to produce considerably over this amount towards the latter end of the period.[1] There was an order in Canada for 50,000 a week, but none had yet been delivered. On March 7, the Minister decided that the home output of 18-pdr. H.E. must be increased from 420,000 to 435,000.[2] The manufacture of 18-pdr. shrapnel was going on well. Canada was already producing 275,000 a week, and 177,000 shell a week were being produced in the United Kingdom, while the latter figure would shortly be improved upon. The allocation therefore remained at 300,000 a week from Canada and 300,000 a week at home.

The home output of 4·5-in. shell which averaged 107,816 H.E. and 1,109 shrapnel per week during February was not very satisfactory, but that was partly due to the shortage of steel. The suggestion that a certain amount of 60-pdr. capacity would have to be transferred to 4·5-in. shell was due to the unsatisfactory position of the 60-pdr. gun, which owing to its popularity, was being worn out at the rate of 37 guns a month. It was difficult to find anyone who would repair this gun, owing to its length, but Sir Glynn West hoped, by installing new machinery, to repair so many 60-pdr. guns that the change-over would be unnecessary. It was decided that the programme for the production of 6-in. shell need not be interfered with. All the arrears on the American contracts for 6-in. shell that could be cancelled had been cancelled, and the 6-in. shell-makers in England, who were making about 135,000 a week, were to be told that they must not increase their output. About 215,000 a week were being reserved from all sources, while the revised programme required 204,000.[3] The 6-in. question could therefore easily be settled.

The extent to which the manufacture of heavy shell should be cut down, however, was a much more difficult question, and the Ministry took the view that if the manufacture of heavy shell were reduced to the figures proposed by the War Office there would be great difficulty in increasing output later in the year, when it was expected that the demand would again increase. This applied in particular to 9·2-in. shell. Sir Glynn West felt confident that by the autumn there would

[1] A.C. 71 (27 March). [2] *Ibid.* [3] A.C. 71 (1 March).

be more 9·2-in. guns in the field than were being reckoned upon, and consequently, a greater expenditure of this nature of ammunition. The heavy shell programme depended on War Office estimates of the life of guns, which constantly varied, while there was evidence that the use of reduced charges and a slower rate of fire would increase the lives of guns by 100 per cent.[1]

There was a large reserve stock of empty shell of these heavy natures, but when, after March, the American deliveries fell off the stock would be gradually reduced to the level of six weeks' supply, which was required to keep the filling factories running smoothly.[2] Moreover, the War Office were asking for a 4-c.r.h. 9·2-in. shell, which could not be easily obtained if the manufacture of 9·2-in. were further reduced.[3] The new type of shell was not easy to manufacture, and there was only a certain amount of machinery on which it could be made.

The committee, therefore, recommended that 9·2-in. shell should be produced at the rate of 42,500 a week, but that this output should be brought down to 37,500, the rate required by the War Office, as soon as possible.[4] As far as possible reductions in output should be made at works other than national factories, in order that these works should be turned over to their ordinary commercial uses, in so far as they were not required for war purposes.

Sir Glynn West, on signing the report, stated that he did not concur with the recommendation as to making the reductions at works other than National Projectile Factories, and that he thought that possibly the reduction in the 8-in. and 9·2-in. shell was too great. The Advisory Committee, however, could see no justification for considering at the moment an increase in the figures recommended, taking into consideration the stocks of heavy shell available or in transit, the difficulty of curtailing the Canadian contracts before the end of June, and the demands for steel for other essential purposes. In order to meet Sir Glynn West's other point, the Advisory Committee added to their recommendation words which exempted privately-owned plant specially constructed for shell production from being changed over to commercial work.

The Minister was unable to accept the committee's recommendations as to the extent to which the manufacture of 8-in. and 9·2-in. shell should be reduced, and, at a conference on 7 March, he decided to raise the weekly rate of output in the United Kingdom to 36,000 instead of 27,000 in the case of 8-in. shell, and to 24,000, instead of 11,600, decreasing to 6,000, in the case of 9·2-in. shell. He also decided that steel or forgings should be substituted for shell as far as possible, in the case of the United States orders in respect of 6-in., 8-in. and 9·2-in.[5]

Later on, however, owing to a reduction in the cross-channel tonnage available, this programme was reduced. The Master-General

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[1] A.C. 71 (February).
[2] *Ibid* (1 March).
[3] *Ibid* (29 February, 1 March).
[4] This meant that the manufacture in the United Kingdom would be reduced from 10,000 to 6,000 a week.
[5] A.C. 71 (12 March); D.M.R.S. 440.

of the Ordnance announced, on 29 March, that the tonnage available in April would only be 5,000 tons a day instead of 7,000, as had been expected, and, in view of this and of the Advisory Committee's representations as to the large stocks of 8-in. and 9·2-in. shell that were in hand, the Minister decided (13 April) to reduce the home manufacturing programme as follows:—8-in. shell from 36,000 per week to 20,000 per week; 9·2-in. shell from 24,000 per week to 5,000 per week.[1]

The question of 12-in. shell was treated on the same lines. At a conference with the War Office, it had been decided that some capacity for making 12-in. howitzer shell should be kept going, in order to provide for an increase of output. If the Germans were driven back to the frontier, 12-in. shells would be wanted, and 38,000 12-in. shells were being sent to Italy. The committee recommended, therefore, that 12-in. shell should be manufactured at the rate of 800 a week, that the remaining capacity should, until required, be utilised for other purposes, and that within the next few months the position should be reviewed.[2] On 7 March, however, the Minister decided that the manufacture of 12-in. shell should be discontinued, the position being reviewed in June.

(b) REDUCED OUTPUT OF HEAVY SHELL.

In order that the change might be made as smoothly as possible the Shell and Components Committee laid down general lines of policy (19 February, 1917).[3] All firms and factories producing heavy shell were to be treated alike, and no preferential treatment was to be given to firms manufacturing their own steel. When plant was unbalanced, the balancing should be downwards rather than upwards. In general, firms and national factories producing heavy shell were to cut down their output to a single shift basis. Both employers and work-people were to be treated with consideration. The necessity for curtailment of output was to be explained individually and personally to the firms and managers of factories concerned, and "the discharge of employees consequent on the reductions should, as far as possible, be effected by omitting to replace those of the workpeople who leave at their own desire, rather than by wholesale dismissals."

The Shell and Components Committee deprecated too drastic a reduction of the actual manufacturing programme, fearing that a revival of demand might be impossible to meet, and the Minister decided on 7 March to allow two thirds of the whole requirements to be met in the United Kingdom. Under these arrangements, the output of empty 8-in. shell was to be reduced from 80,000 a week to 60,000 a week, of 9·2-in. shell from 63,000 to 55,000, and of 12-in. howitzer from 5,000 to 1,000 a week, but the losses of shipping in April made a further reduction imperative, and the Ministry decided (24 April) that shell manufacture must be reduced to 20,000 8-in. and 5,000 9·2-in. per week, though filling would be at the rate of 45,000 and 30,000 a week

[1] A.C. 71 (16 April). [2] *Ibid* (2 March).
[3] Shell and Components Committee Minutes, 19 February, 1917.

respectively. This was made possible by the fact that large stocks of empty shell (561,000 8-in. and 332,000 9·2-in.) were in existence.[1]

A conference with representatives of National Projectile Factories and certain assisted contractors was held on 21 March, when the position was explained and information supplied as to the manufacturing programme and supplies of steel available.[2] Very elaborate re-allocation work was entailed by the March and April reductions in the manufacturing programmes,[3] some of the national factories being turned over to gun repair, some to marine engine work and others to aircraft work.

(c) Increased Output of Light Shell.

This transfer of shell-making capacity chiefly affected heavy shell plant. The demand for light shell increased rather than diminished in 1917,[4] and, in addition to changing over certain of the National Projectile Factories to 18-pdr. shell,[5] it was decided that 18-pdr. shell plant in the hands of private contractors should be balanced up by the provision of additional machines, in order to obtain the best possible output.

The problem of working up the output of 18-pdr. H.E. to the required level was a very serious one. If Canada supplied the anticipated 50,000 a week, 550,000 a week would have to be manufactured at home, and Sir James Stevenson thought it was quite impossible to reach this figure, as the best output that had ever been reached, even including the armament firms (who had been turned over to shrapnel) had been 500,000 a week.[6] Output had been reduced to a very low level, the production when the first 1917 programme was launched being about 101,000 per week.

The position with regard to 4·5-in. shell was also difficult, the requirement under the programme being 310,000 a week. There was some difference of opinion between Sir Glynn West and Sir James Stevenson as to the possible output in the United Kingdom. The former estimated the total capacity of the existing plant at 180,000 a week, and suggested ordering 154,000 a week in Canada; Sir James Stevenson thought the limit of home capacity was 150,000. On enquiry this latter figure was accepted[7] and the remaining 160,000 a week were therefore ordered in Canada, which already had a capacity of 115,000 weekly.

The chief sources of supply of 18-pdr. and 4·5-in. shell were, of course, the Boards of Management. Their efforts to increase the output of 18-pdr. and 4·5-in. shell in the late autumn of 1916 have already been dealt with, their comparative failure being due to the fact that much of the machinery used in producing 18-pdr. shell had been dispersed, and that even when the factories, which had been turned off light shell, were ready to begin production again, the supplies of steel

[1] Letter from Ministry to War Office, 24 April, 1917 (D.M.R.S. 440.C.).
[2] (Printed) *Weekly Report*, No. 84, II (17.3.17).
[3] For tables summarising these arrangements, *see* Hist. Rec./H/1300/15.
[4] Vol. X, Part II, Chap. I.
[5] *See* below, p. 54.
[6] A.C. 2 (23 October, 1916).
[7] A.C. 4, 152 (23, 24 and 26 October).

were utterly inadequate.[1] Even when the programme was reduced to 435,000 a week (March, 1917) the position remained difficult. Owing to the delay in working up output it was clear that shell would have to be manufactured at a much higher rate, during the later months of the year and it was hoped that a total output, from all sources, of approximately 750,000 18-pdr. H.E. shell would be reached ultimately. Part of the supplies of steel for 8-in. and 9·2-in. shell were to be diverted to the lighter shell, and the Steel Department promised to provide steel for an average weekly output of 430,000 a week for the 24 weeks from 14 April onwards, and hoped after that date to provide steel for 650,000 a week.[2] Boards of Management were to be told that the Ministry looked to their contractors for an output of 350,000 18-pdr. H.E. a week, and that, unless their production was quickly increased, the Ministry would develop other machining capacity at once.

Their own estimate of the development of their output of 18-pdr. shell was as follows :—

April	165,000
May	253,000
June	304,000
July	322,000
August	328,000
September	350,000[3]

The Board of Management contractors were visited by the Superintending Engineers of their areas ; and all contractors for light shell were asked to take early steps to train labour for night shifts. In order to encourage contractors to incur the expense of training labour for night shifts afresh, they were informed, as soon as possible, that they would be given continuation contracts from 1 July to 30 September.[4]

This pressure to produce at full capacity continued, and in June circulars were sent to all Boards of Management to find out whether there were any of their contractors who did not propose to introduce double shifts. They were to be informed that after 30 June, except in special cases, all contracts for 4·5-in. shell were to be placed for the full capacity of the contractor's plant including a night shift.[5]

The growing output of 18-pdr. and 4·5-in. shell by Boards of Management may be followed in the tables of gun ammunition output. On 18 June it was reported that the balancing up of 18-pdr. plant was practically completed, very few tools being outstanding.[6]

(*d*) ATTEMPT TO REDUCE CONTRACT PRICES.

At this very inopportune moment, from the supply point of view, the Contracts Department proposed a further reduction in the contract prices of 18-pdr. H.E. shell for the period 1 July to September 30. Sir Glynn West protested on the ground that 18-pdr. shell was urgently

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[1] *See* above, p. 41.
[2] Shell and Components Committee, Weekly Report, 19 March (23), 14 April.
[3] *Ibid*, 26 March, 2 April, 23 April, 1917.
[4] (Printed) *Weekly Report*, No. 85, II (24.31.7).
[5] Shell and Components Committee Minutes, 29 May, 4 June.
[6] *Ibid*, 18 June (350).

wanted and that the Ministry was asking for increased output and extra labour shifts. This view prevailed, and continuation contracts from 1 July to 30 September at the old prices were arranged.[1]

The Contracts Department, however, renewed their attempt to reduce prices and a sliding scale of prices for 4·5-in. shell for Board of Management contractors came before the Shell and Components Committee on 2 May. It was criticised on the ground that the reduction of price for an increased output tended to discourage production and penalise efficiency, and the Contracts Department were asked to reconsider the point.[2]

Side by side with these efforts to increase production by the Board of Management contractors, steps were being taken to place large contracts for 18-pdr. H.E. shell with direct contractors.[3] It was clear, however, that even if the Boards of Management produced all that was expected from them, and the direct contractors also, there would still be an ugly gap between supply and demand. An important decision was therefore taken—to change over part of the capacity of the National Projectile Factories to the production of light shell. The factories affected were Birtley, Dudley, Cardonald, Mile End (Glasgow) and Templeborough.

By 23 May it was reported that the arrangements already made with direct contractors and National Projectile Factories provided for a weekly output of from 262,000 to 272,000 18-pdr. H.E. shell, which had involved a total capital expenditure on plant and machines of approximately £19,650.[4] Another source of supply was found in the capacity of contractors who had been employed on 13-pdr. H.E. and shrapnel and 2·75-in. H.E. shell. Their existing contracts were cancelled and they were given an opportunity of turning over to 18-pdr. H.E., full supplies of steel being promised them.

Since 4·7-in. shell was obsolescent there was an opportunity of increasing the output of 4·5-in. shell by changing over firms who held 4·7-in. contracts[5]; but the Contracts Department did not immediately cancel all contracts for 4·7-in. shell in view of the disorganisation of the works and the danger of losing labour which might later be wanted for shell manufacture.

(e) Supply of 18-pdr. Shrapnel.

The stock of 18-pdr. shrapnel was diminishing rapidly in the winter of 1916, owing to the high rate of expenditure in France. During October, issues had averaged 681,000 a week, and as such over-issues would completely upset all calculations, the Shell Manufacture Department urged that it was absolutely necessary not to issue more than 600,000 a week, and if possible to reduce issues during the winter months to 500,000 a week. Even if the estimated home output was reached[6]

[1] Shell and Components Committee Minutes, 2 April. [2] *Ibid*, 23 May.
[3] *Ibid*, 14 May, 23 May (261, 282); C.S.M. 30579; 94/S/5800; P.M./S/8570.
[4] Shell and Components Committee Minutes, 22 January, 16 April, 23 May.
[5] *Ibid*, 2 April (174).
[6] The home output was 115,000 in October (Advisory Committee Minutes, 23 October) and 122,000 a week in November, and it was estimated that it could be brought up to 250,000 a week by April.

there was not much margin to work upon, and no allowance had been made for losses in transit from the United States of America, where 18-pdr. shrapnel contracts terminated in January, and from Canada.

By 29 January, 1917, orders had been placed for 18-pdr. shrapnel with nine Munitions Committees, with Messrs. Vickers, Armstrong, Beardmore, Dorman Long, Ferranti, the Phœnix Dynamo Company and the North Eastern Railway Company for 372,000 rounds a week, while 300,000 complete rounds were ordered from Canada. In the spring of 1918, an order for 2,000,000 complete rounds was placed in Canada, negotiations with the Bethlehem Steel Company having been abandoned owing to the high price asked.[1]

IV. Release of Shell Making Capacity.

As has been seen, the reduced programme for heavy shell set free a certain amount of shell-making capacity. By 19 March it had been decided that gun-repair should be undertaken at the following National Projectile Factories—Lancaster, Cardonald, Sheffield, Nottingham and Leeds.[2] Dudley also undertook the manufacture of gun parts, and later part of Hunslet National Projectile Factory was also taken for gun-repair work.[3]

The shell plant at the Nottingham National Projectile Factory was dismantled by degrees, a weekly output of 5,000 9·2-in. shell and of 13,500 6-in. shell having been reached on plant designed to produce 2,000 9·2-in. and 6,000 6-in. The installation of the gun-repairing plant at Nottingham was complete by 20 June. The factory proved so successful with gun repair work that it was later transformed into a gun factory for the manufacture of 18-pdr. and 6-in. guns, and from 1 October onwards was classed as a National Ordnance Factory.[4] Similarly, Messrs. Hadfield's factory at Sheffield and the Hunslet factory at Leeds took up gun manufacture and became National Ordnance Factories, the former undertaking 60-pdrs., and the latter principally 18-pdr. guns.[5]

Gun-repair, however, did not absorb all the shell capacity available for transfer, and on 24 April, 1917, the Minister asked the Advisory Committee "to investigate the redundant resources set free by the reduction of the programme, to ascertain the unsatisfied requirements of the Ministry and to consider and report to what extent the latter can be met by the former." For the purposes of this reference the Controller of Shell Manufacture and the Controller of Aeronautical Supplies were added to the Advisory Committee.[6]

Suggestions for utilising this surplus capacity had already been invited from other departments of the Ministry. The most important proposals came from the Railway Materials Department, the Director of

[1] Cables. N.Y. 29572. 31 October, 1916.
[2] Shell and Components Committee Minutes, 19 March, 1917.
[3] A.M.3/Hunslet/P. 21.
[4] Report on National Ordnance Factory, Nottingham, by Messrs. Cammell, Laird.
[5] C.G.M. 387/2; Vol. VIII, Part II.
[6] A.C. 93.

Aeroplane Construction and the Trench Warfare Supply Department. The general policy which was to govern this transfer of capacity was debated at some length. The Controller of Shell Manufacture's view was that certain of the National Projectile Factories must be kept intact as a precautionary measure. They could act as machining sub-contractors to do any miscellaneous work of which they were capable, the responsibility for ordering material remaining with the department which ordered the work to be done. The work would be done more cheaply in the National Projectile Factories than if the machines were transferred to the private firms. There was also the powerful argument that much more use was made of women's labour in national factories than in factories belonging to private firms. Other members of the committee thought it would be better to transfer the machines outright to industrial firms who were overwhelmed with work.[1] The Controller of Aeronautical Supplies, for instance, argued that it would be better to transfer any suitable machinery to firms who specialised in the production of finished locomotives, rather than to undertake the machining of locomotive parts in National Projectile Factories, which would have to be finished and assembled elsewhere, thus increasing transport difficulties. The Director-General of the American and Transport Department agreed with this to some extent, but pointed out that the locomotive makers were "proficient in nothing except excuses," and their output as compared with that in the United States was lamentably small. As a result of these deliberations, the Cathcart National Projectile Factory was turned over to aeroplane work, the Daimler Company's shell shop was converted for turning crank shafts for aeroplane engines, and another shell shop returned to its former work of making railway wagons.[2]

Owing to the shortage of ball bearings the possibility of using shell-making plant for the production of ball bearings was discussed, but as they were not equipped for the production of the highest grade ball races nothing came of this suggestion. A certain amount of miscellaneous work was done for the Trench Warfare Supply Department, and the manufacture of mines for the Admiralty was projected but later abandoned.[3]

These arrangements for transferring whole factories from shell to other munitions work having been made, Sir Glynn West's plan for keeping the shell plant in other National Projectile Factories intact, but using it for other work, was adopted. On 30 April, therefore, the Advisory Committee made the following recommendations to the Minister :—[4]

(1) "That a Miscellaneous Demands Section under its own Director be set up in the Department of the Director-General of Shell Manufacture, to undertake as a contractor for the various Supply Departments of the Ministry, (and, if necessary, for their contractors) such work as can be done

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[1] A.C. 93 (26 April, 1917).
[2] A.C. 93 ; Shell and Components Committee Minutes 210, 316.
[3] A.C. 93 (26 April).
[4] *Ibid.*

in the National Projectile Factories on the machines rendered available by the reduction in the gun ammunition programme.

(2) "That a statement in general terms of the class of work which can be undertaken by the Miscellaneous Demands Section be circulated to the Supply Departments, the Requirements Department and the Clearing House with a request that, if any of their requirements come within the scope of the capacity of the section, they should at once communicate with the section in order to ascertain if and to what extent the requirements can be undertaken at the National Projectile Factories.

(3) "That a schedule of the machinery belonging to the National Projectile Factories, showing the machinery :—

(*a*) being used for shell manufacture,
(*b*) being used for the manufacture of other munitions,
(*c*) spare,

be sent to the Clearing House and that instructions be given that applications for machines for work of a similar type to that capable of being done in National Projectile Factories, should be referred before being agreed to, to the Miscellaneous Demands Section in order to ascertain whether arrangements cannot be made for the utilisation on this work of the machining capacity available in these factories.

(4) That the Director-General of Shell Manufacture report fortnightly to the Minister the requirements he has undertaken to supply for each Department and the proportion of spare capacity still remaining to be utilised.

(5) "That none of the machinery belonging to the National Projectile Factories be sold without the special authorisation of the Minister."[1]

These recommendations were accepted by the Minister, who proposed that Mr. Maclean, the Deputy Controller of Shell Manufacture, should control the Miscellaneous Demands Section. A memorandum issued on 19 May to take effect from 21 May,[2] set out the work that the National Projectile Factories were able to undertake as follows :—

(*a*) Forging and pressing up to 24-in. diameter.
(*b*) Turning and boring up to 15-in. diameter.
(*c*) Facing work up to 24-in. diameter.
Drilling work up to 1½-in. diameter.
(*d*) Small machined parts for such machines as automatics and capstan machines up to 6-in. diameter.
(*e*) Assembling such work.

The transfer of some of the National Projectile Factories to gun repair and other work involved the storing of a certain amount of shell-making machinery. A complete record of the plant and machines

[1] Sir William Weir did not concur in making this recommendation.
[2] General Memorandum, No. 6 (19 May, 1917).

stored was prepared, and lists were sent to the Machine Tool Department and the Central Clearing House,[1] who added them to their list of available machinery and prepared to issue them as required to applicants. It was suggested that the Stores Department should be responsible for keeping the machines in good condition.[2]

The elaborate re-arrangements outlined above resulted in a great increase in the output of light shell. When the home production of all natures reached its maximum, in December, 1917, a reduction in the gun ammunition programme was on the eve of taking effect, and by February, 1918, the total output of 18-pdr. and H.E., and of 4·5-in. H.E. was respectively 70 per cent. and 55 per cent. in excess of the reduced programme. The only nature in which the production of shells was short of the filling programme was the 6-in. howitzer. This was partly due to the failure of American contractors to deliver up to contract, and partly due to tonnage difficulties in importing from Canada.[3] The production of components was very satisfactory, and very large stocks of H.E. fuses, cartridge cases and primers having been accumulated, manufacture was cut down. On the other hand, the supply of chemical and smoke shell was far below expectations. The programme was about four months late in maturing, and there was little hope of providing the stocks which should have been available for the beginning of the 1918 campaign. During 1918, therefore, the chief energies of the Shell Manufacture Department were concentrated upon the production of chemical shell and of long range shell.[4] The production of the ordinary types had been put upon a sound basis and required but little attention. As the prospect of maintaining the output of ammunition in 1919 on the 1918 level was unfavourable, owing to the prospective shortage of steel and of shipping, it was decided at a conference at G.H.Q. (April, 1918) that ammunition was to be saved if possible and accumulated for the 1919 campaign.[5]

V. Chemical, Smoke and Incendiary Shell.

(*a*) Chemical Shell.

The greatly increased demand for chemical shell in the latter half of 1917 and during 1918 was reflected in the work of the Shell Manufacture Department, and throughout the period the task of finding contractors to produce experimental shell in small quantities and finally to produce in bulk was no light one. A large number of contractors were turned over from H.E. shell to chemical shell, but many new contractors had to be found. During this period the double diaphragm type of steel shell was being rapidly replaced by the container type, and new types of chemical shell in cast iron, also of the

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[1] Shell and Components Committee Minutes, 23 April (209). A general procedure minute was issued laying down rules for the custody and disposal of this plant (*Ibid.*, 11 June (336)).

[2] A.C. 93 (26 April).

[3] Hist. Rec./R/1000/63 (February, 1918).

[4] A large amount of experimental work was done by the National Projectile Factories (A.M.3 A. Committee Minutes, 7 June, 1918).

[5] D.M.R.S. 535, II.

container type, were being produced for many natures.[1] As in the case of long range shell[2] much experimental work was undertaken by National Projectile Factories—Lancaster, Hackney, Birtley and Dudley—and the production of chemical shell on a considerable scale was undertaken by various Boards of Management.

At the beginning of 1917, 60-pdr. and 4·5-in. chemical steel shell of the double diaphragm and container types were being made, as well as 4·5-in. chemical shell in cast iron.[3] This was the extent of the demand for chemical shell, but 1917 and 1918 saw the introduction of new types of cast iron shell of these calibres and the adoption of chemical shell for other weapons, the field gun, the 6-in. howitzer, the 9·2-in. and the 8-in. howitzer, most of these shell being made in cast iron. In June, 1917, it was decided that 60-pdr. chemical shell was to be gradually superseded by 6-in. chemical, which was to be made in cast iron. It was not thought worth while, therefore, to begin making the 60-pdr. chemical shell in cast iron,[4] and when the demand for 60-pdr. chemical shell revived in May, 1918, steel shell were supplied.[5] In September, 1918, 60-pdr. chemical steel shell was being supplied by the Ordnance Factories and by the Projectile Company.

There was an urgent demand for 6-in. chemical shell in March, 1918. The War Office requirement was 51,000 a week, but supply in the week ending 9 March was only 17,100.[6] Special efforts were made to hasten output and speed up transport.[7] 6-in. shell was the first shell to be filled with mustard gas (H.S.).[8] Though experiments with 8-in. and 9·2-in. chemical cast iron shell were being carried on in 1918 at Lancaster and Birtley, up to the date of the Armistice the only chemical shells which were being manufactured for these larger natures were steel shell, orders for which at the rate of 6,200 9·2-in. and 7,000 8-in. were being placed in July, 1918, as follows :—[9]

9·2-in. *Chemical* 4 *c.r.h.*	8-in. *Chemical* 4 *c.r.h.*
Messrs. Asquith & Co.	Messrs. Beardmore.
British Westinghouse Co.	Ponders End Shell Works.
Dublin National Shell Factory.	
Phœnix Dynamo Co.	
Messrs. Vickers.	

Owing to the shortage of steel, certain marks of H.E. shell were converted to chemical shell wherever possible;[10] 60-pdr. and 6-in. shell were being converted in this way in July, 1918. It was decided that all H.E. shell (except 18-pdr.) rejected for thin bases should,

[1] It was decided (4 January, 1918) that owing to the shortage of steel, cast iron or semi-steel must be used for chemical shell. Co-ordinating Committee Minutes, 7 June, 1918 (M.C. 326).

[2] *See* below, p. 63.

[3] *Order and Supply Lists*.

[4] A.M.3 A. Committee Minutes, 4 July, 1917.

[5] Chemical Shell Committee Minutes, 22 May, 1918; Co-ordinating Committee Minutes, 14 May.

[6] Chemical Shell Committee Minutes, 16 August.

[7] Co-ordinating Committee Minutes, 25 March.

[8] *Ibid.*, 18 June.

[9] Chemical Shell Committee Minutes, 15 May, 10 July, 1918.

[10] A.M.3 A. Committee Minutes, 1 July, 1918; A.M.3 C./C.S.M./20802.

within certain limits, be converted into chemical shell,[1] and later that howitzer shell with ghost lines, and rokey howitzer shell below 8-in. which passed the hydraulic test might be accepted for chemical filling.[2] Rokey 18-pdr. gun shell might be converted for smoke filling only.[3]

The chief difficulty from the supply point of view in the production of cast iron shell for chemicals was the shortage of cast iron of the very high quality required.[4] The maximum phosphorus content was ·8 per cent., which could not be produced without using 25 per cent. to 40 per cent. of hematite pig iron.[5] Certain firms making castings for these shell refused to do either 4·5-in. or 18-pdr. castings unless the percentage of phosphorus was raised, and a report, dated 11 October, 1918, shows that many of the contractors for castings found the work difficult. The Design Department was asked to allow a higher percentage of phosphorus, and after a series of successful experiments with shell made from this material,[6] this was conceded just before the Armistice. The phosphorus content was increased to 1·1 per cent., a special compression test being required.[7] Another concession was that cast iron shells suspected of porosity might be fitted with base plates and accepted, if they passed suitable tests.[8] The collection of steel scrap from National Projectile and Shell Factories also went some way towards solving the problem of getting suitable material for the manufacture of cast iron shell.[9]

The manufacture of experimental cast iron chemical shell for the 6-in. howitzer was proceeding at Dudley National Projectile Factory in July, 1917,[10] and later on orders for this shell up to a total of 45,900 a week were placed with the Carron Company, Messrs. Marshall & Sons, the Pelabon Works and the Phœnix Dynamo Company. Chemical shell for the 6-in. gun had been ordered in July, 1918, from the Projectile Company and deliveries were just beginning at the date of the Armistice,[11] while cast iron chemical shell for the 4·5-in. howitzer was ordered at the rate of 32,750 a week from various Munitions Committees, from the Ordnance Factories, and Messrs. De Dion Bouton.[12] In October deliveries of this shell, in steel and cast iron, were being made at the rate of 36,000 a week.[13]

Steel chemical shell for the field gun came into supply in July, 1918.[14] Cast iron shell for this weapon had been ordered in April from nine Munitions Committees, from Keighley National Shell Factory, and from a number of engineering firms, the orders placed by July amounting

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[1] Chemical Shell Committee Minutes, 5 June, 1918.
[2] *Ibid.*, 16 August. [3] *Ibid.* [4] *Ibid.*, 22 May.
[5] Co-ordinating Committee Minutes, 20 December, 1917.
[6] Chemical Shell Committee Minutes, 15 May, 3 June, 22 July, 16 August, 1918.
[7] *Ibid.*, 1 November.
[8] *Ibid.*, 11 October.
[9] *Ibid.*, 22 July.
[10] A.M.3 A. Committee Minutes, 4 July, 1917.
[11] *Ibid.*, 8, 15, 22 July, 1918; Chemical Shell Committee Minutes, 14, 20 September, 11 October, 1918.
[12] Chemical Shell Committee Minutes, 22 May, 1918.
[13] *Ibid.*, 11 October, 1918.
[14] A.M.3 A. Committee Minutes, 1 July, 1918.

to 57,750 a week.[1] This shell was very successful and a demand for 150,000 a week was received in September.[2]

The growth in the output of chemical cast iron shell during 1918 appears from the following figures :—

Date.	Weekly Output.	Tonnage of Cast Iron.
February, 1918	29,000	1,000
September, 1918	57,000	2,845

(b) SMOKE AND INCENDIARY SHELL.

An urgent demand for smoke shell was dealt with in January, 1917. Fifty thousand a week were required, but the supply was governed by the amount of phosphorus obtainable, which was then uncertain. The requirement was allocated among certain Boards of Management and the Phœnix Dynamo Company, and by 29 January arrangements had been made for the supply of 24,000 a week, with firms working double shift.[3] As soon as the required amount of phosphorus was obtained, contract arrangements for a further supply were pushed on with all possible speed.[4] A record production of 25,000 was reached in the week ending 5 May.[5]

Steel 18-pdr. smoke shell was only made in small quantities in 1918, the Boards of Management and the Phœnix Dynamo Company being turned over to 18-pdr. H.E., but just before the Armistice a demand for 5,000 a week was received. Experiments with 18-pdr. cast iron shell for smoke filling failed to produce a satisfactory design. In the meantime, 4·5-in. smoke shell in steel and cast iron was being made by the Manchester Munitions Committee and by the Phœnix Dynamo Company, and, in September, this shell was being produced at the rate of 17,560 a week in July.[6]

Contracts for 18-pdr. incendiary shell to meet a demand for 100,000 were placed with Messrs. De Dion Bouton, who undertook to produce part of this output of shell by converting 18-pdr. shrapnel bodies.[7] They began delivering this shell in July. Incendiary shell for the 4·5-in. howitzer was also asked for and the Ailsa Craig Factory began delivering shell of this type in September.[8]

[1] *Order and Supply Lists*; A.M.3 A. Committee Minutes, 22 March, 1918; Chemical Shell Committee Minutes, 22 May, 28 October; A.M.3 A./Chemical/200.

[2] Chemical Shell Committee Minutes, 27 September.

[3] *Order and Supply Lists.*

[4] Shell and Components Committee Minutes, 29 January (21).

[5] (Printed) *Weekly Report*, No. 90, II (5.5.17).

[6] P.M./Man/1684; P.M./S/11960; Chemical Shell Committee Minutes, 10 July, 1918.

[7] Minutes of Heavy Gun Shell Committee, 11 June, 9 July, 30 July, 16 August.

[8] Minutes of Heavy Gun Shell Committee, 16 August, 6 September, 1918; A.M.3 A. Committee Minutes, 22 July.

The following tables show the total output of chemical, smoke and incendiary[1] shell to December, 1918 :—

Nature.	1916.	1917.	1918.	Total.
18-pdr. Chemical	—	—	576,100	576,100
Smoke	100	1,397,200	307,200	1,704,500
Incendiary	—	—	84,500	84,500
4·7-in. Chemical	92,600	26,300	—	118,900
Incendiary	—	—	1,000	1,000
60-pdr. Chemical	119,200	576,000	245,000	940,200
4·5-in. Chemical	497,800	785,700	1,671,500	2,955,000
Smoke	—	152,200	446,200	598,400
Incendiary	47,300	2,500	5,000	54,800
6-in. Gun. Chemical	—	—	10,200	10,200
How. Chemical	—	120,000	2,213,500	2,333,500
Incendiary	—	100	23,900	24,000
8-in. Chemical	—	—	1,200	1,200
9·2-in. Chemical	—	—	7,000	7,000
2·75-in., 3-in., 18-pdr. A.A. Incendiary	14,000	161,500	209,600	385,100
Grand Total Chemical ..	709,600	1,508,000	4,724,500	6,942,100
Grand Total Smoke ..	100	1,549,400	753,400	2,302,900
Grand Total Incendiary ..	61,300	164,100	324,000	549,400

VI. Long Range Shells.

As has been seen, the Army had been pressing for long range shells from 1916 onwards, and to meet this demand designs of shell were gradually lengthened, the 2 c.r.h. type which was normal in 1914 and 1915 being replaced by 4 c.r.h. and 6 c.r.h. types in 1917,[2] while in 1918 8 c.r.h. types were being introduced.

Shells with 6 c.r. heads were being supplied in the following natures at the date of the Armistice :—

9·2-in. gun, H.E. and shrapnel.
6-in. gun, H.E. and shrapnel.
6-in. gun and howitzer, chemical.
4-in. A.A., incendiary.
4-in. A.A., shrapnel.
3-in. 20-cwt. A.A., shrapnel and chemical.
75-mm., chemical, incendiary and shrapnel.
13-pdr. 9-cwt., chemical.
12-pdr. 12-cwt., star shell.

The first nature of shell to be ordered in bulk in the 8 c.r.h. type was the 60-pdr. Six thousand a week were ordered from the Ordnance Factories in June, 1917,[3] and from this date all contracts for 60-pdr. H.E. and shrapnel shell were for 8 c.r.h. shell. The design for 8 c.r.h.

[1] Including star shell.
[2] The change from 2 c.r.h. to 4 c.r.h. in 8-in. and 9·2-in. shell was made in July, 1917 (A.M.3(A.)/4740; A.M.3(A.)/4739).
[3] A.M.3 A. Committee Minutes, 6 June, 1917.

12-in. H.E. and shrapnel had been approved by 14 May, 1918, but pending firing trials manufacture could not begin.[1] Orders for shell of this type were given to the Newlay National Projectile Factory, in August.[2]

Meanwhile, experimental 12-in. shell (8 c.r.h.), which gave a range of about 30,800 yards, fitted with ballistic caps were being made by Messrs. Hadfield and by the Renfrew National Projectile Factory.[3] There were difficulties in welding the ballistic caps, and the Design Department were asked to approve brazing in lieu of welding for the experimental shell.[4] Experiments with 6-in. howitzer shell fitted with ballistic caps began at Hackney Marshes in September, the shell being made to two designs. One lot of shell was made to each design with the caps numbered to correspond with the shell to secure concentricity, and a second lot with caps selected at random and tested for eccentricity. Similar experiments were carried out with 8-in. shell.[5] The 6-in. shell were ready for trials by 1 November and new designs were submitted by the Birtley, Dudley and Lancaster National Projectile Factories about the same date.

Stream line designs—that is, shells with their base sloped in a special way—which gave still greater length were also being experimented with. There was some controversy as to the accuracy of this shell, but on 10 August, 1918, the Army Council stated that the provision of stream line shell for siege guns and howitzers was of the first importance. The 6-in. howitzer stream line shell was 9·25 c.r.h.;[6] the stream line shell for the 6-in. gun was 7 c.r.h., and the 18-pdr. stream line shell was 7·57 c.r.h. Experimental stream line shell for the 12-in. gun was being made by Messrs. Hadfield and by the Renfrew National Projectile Factory in August and September, 1918.[7] It was hoped that a small amount of stream line shell for the 6-in. howitzer would be available for filling in November, and that an output of 10,000 a week would be reached in January. The War Office stated (10 October) that if this type of shell was satisfactory in the field, the whole of the ammunition for the 6-in. howitzer would be stream line.[8]

VII. Miscellaneous Demands.

As a reply to the German use of concrete pill boxes, a considerable demand for armour-piercing shell for land service developed in 1918,[9]

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[1] Minutes of Heavy Gun Shell Committee, 14 May, 21 May, 11 June, 23 July, 1918.

[2] *Ibid.*, 16, 30 August, 20 September, 1918. Long range shells for the 12-in. gun were given precedence over shells for the 14-in. guns, as deliveries of the latter gun were slow and it could not be re-lined, 15 April, 1918 (D.M.R.S. 535, II).

[3] *Ibid.*, 25 May, 23 July, 16 August, 27 September, 1918.

[4] *Ibid.*, 4 October.

[5] *Ibid.*, 14, 20 September, 1918.

[6] War Office letters, 10, 20 August and 7 October (D.M.R.S. 440). The demand for this shell was received in August 1918, and orders were placed with the Birtley and Hackney Marshes factories.

[7] Minutes of Heavy Gun Shell Committee, 28 May, 23 July, 16 August, 20, 27 September, 1918.

[8] War Office letter, 10 October, 1918 (D.M.R.S. 731/B.).

[9] Conference at G.H.Q., France, 19 March, 1918.

the shell being either A.P.C. or C.P.C.—armour-piercing or common pointed capped shell. A demand for A.P.C. and C.P.C. 9·2-in. gun shell was received in the spring of 1918.[1]

There was an outstanding order for armour-piercing shell with Messrs. Armstrong Whitworth, but it was difficult to find other contractors for this shell, which needed great skill in manufacture, the tests requiring that the whole shell should pass through a plate without breaking up.[2] Messrs. Hadfield undertook to make 20,000 common pointed capped shell (the tests for which were less severe) by 31 March, 1919, but were unwilling to undertake armour-piercing capped shell, as well. Messrs. Vickers also refused to make this shell, but a contract for 1,500 was undertaken by Messrs. Firth (6 September, 1918). Messrs. Hadfield began delivering 9·2-in. C.P.C. shell early in October.[3]

The three months keeping test required by the Ordnance Committee for this nature of shell created difficulties. It was stated (21 May, 1918) that the Admiralty no longer required a keeping trial, and the Shell Manufacture Department therefore asked the Design Department to make this concession. The Ordnance Committee decided that the shell might be accepted from the makers after a special temperature trial, but must undergo the keeping trial in a Ministry store.[4]

Armour-piercing shell was also made for the 6-in. gun, for the 8-in. howitzer, and for the 12-in. gun and howitzer.[5] On 20 July, 1918, the Army Council emphasised the importance of the provision of this type of shell.[6]

One of the miscellaneous demands which caused considerable supply difficulties in 1917 and 1919 was that for 6-pdr. ammunition for tank guns which required very high quality steel and a base fuse. The first demand dated from the spring of 1916.[7] In September, 1,000,000 rounds were asked for, the number being reduced later (28 November) to 600,000. On completion of this, running orders were given for 40,000 a week. Cast iron shell were ordered for use in training in order to economise this special quality steel and were made by various Boards of Management.[8] The requirements for 1918 were 600,000 for fighting, and 270,000 for training, and during September, 1918, shells of this type were being produced at the rate of 15,500 a week, by the Ordnance Factories, by Messrs. P. Garrett & Sons, by the Pelabon Works, and by Messrs. Vickers (of Stockport).[9]

Among the other types of shell made in comparatively small quantities in 1918 were various calibres of star shell (6-in., 4·7-in.,

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[1] A.M.3 A. Committee Minutes, 26 April.

[2] *Ibid.*, 1 July, 15 July, 1918; Minutes of Heavy Gun Shell Committee, 14 May, 1918.

[3] *Ibid*, 4 October, 1918.

[4] Minutes of Heavy Gun Shell Committee, 21 May, 4 June, 11 June, 30 August, 14 September, 1918.

[5] A.M.3 A. Committee Minutes, 26 April, 10 May, 1 July, 15 July, 1918; Minutes of Heavy Gun Shell Committee, 14 May, 1918.

[6] D.M.R.S. 540/X.

[7] *See* above, p. 26.

[8] P.M./Birmingham/2106; P.M./Coventry/286; P.M./East Anglia/405.

[9] P.M./S/12061.

4·5-in., 18-pdr., 3-in., 2·75-in., and 6-pdr.), the 75 mm. H.E., smoke and incendiary shell, shell for the 2-pdr. Q.F. aeroplane gun, 1·59-in. H.E. and armour-piercing shell, 1½-pdr. H.E. shell,[1] and 4-in. H.E. and incendiary shell.[2]

Among the shell which had passed the experimental stage, but had not come into supply in any considerable quantity, was the 14-in. gun shell.[3] A certain number of Admiralty shell were fired during the summer, but as this source of supply was nearly exhausted, the Ministry urged on production, and the first delivery was made in the week ending 14 September, 1918.[4]

During January, 1917, arrangements were made to supply a large quantity of rough turned 210 mm. and 105 mm. forgings for Italy, and a supply of 27,000 finished 305 mm. shell with fuses was also arranged, so that the whole would be shipped by the end of February.[5] A little later (3 February) a shipment of empty 12-in. shell and a large consignment of empty 6-in. gun shell were asked for. This latter requirement was not easy to meet, as a large proportion of the 6-in. Mark XVI. shell had been sentenced by the Inspection Department as suitable for use in the 6-in. howitzer only, on account of their being made from steel of a low yielding point.[6]

Thirty thousand finished 152 mm. shell were shipped during February and March. When gun-repair work was undertaken by some of the larger shell plants, arrangements for meeting the Italian requirements had to be modified. Arrangements were made for producing 80,000 149 mm. shell at the Nottingham National Projectile Factory, and other shell requirements were undertaken by the Cardonald Factory, which started on the work within a fortnight of undertaking it.[7] By 10 March, it was reported that the results of the trials of the sample 149 mm. shell sent out to Italy had been highly satisfactory.[8] The urgency of the demand for these Italian shells was emphasised on 17 March, and satisfactory promises of early delivery were made by the Cardonald and Nottingham National Projectile Factories.[9] All the fuses required for the 305 mm. and for the 152 mm. shell had been shipped by 14 April, and the only item of the requirements that was causing anxiety was the requirement for 260 mm. head forgings, which had been delayed by the strike at Barrow. Unfortunately, about 3,500 of the 305 mm. shells were lost at sea (about 28 April).[10]

During 1917 and 1918 there was a great increase in shell production in Canada, and a diminution in American orders. Canadian shell

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[1] This was originally known as the 37 mm. shell.
[2] A.M.3 A. Committee Minutes.
[3] *Ibid.*
[4] Minutes of Heavy Gun Shell Committee, 14 September, 1918.
[5] (Printed) *Weekly Report*, Nos. 77, II. (27.1.17).
[6] *Ibid.*, No. 78, II. (3/2/17).
[7] *Ibid.*, No. 82, II. (3.3.17).
[8] *Ibid*, No. 83, II. (10.3.17).
[9] *Ibid.*, No. 84, II. (17.3.17).
[10] *Ibid.*, No. 89, II. (28.4.17).

was cheaper than American shell.[1] Again, heavy indebtedness in Canada was financially preferable owing to the credits given by the Dominion Government, while the money so spent would remain in Allied territory and was still available for the purposes of the war.[2] The shell orders on which Canada was then working were, therefore, largely increased in October.[3]

VIII. Shell Production in the Autumn of 1918.

The following table is of interest as a summary of the supply activities of the Gun Ammunition Department just before the Armistice :—

Nature.	Average Weekly Output from all Sources in September.	Weight of Steel Used. (Tons).
15-in. How. H.E.	216	240
12-in. Gun H.E.	178	120
12-in. How. H.E.	1,007	527
9·2-in. Gun H.E.	2,091	617
S.	188	41
9·2-in. How. H.E.	24,951	5,462
8-in. How. H.E.	35,294	5,189
6-in. Gun H.E.	10,846	878
S.	8,461	437
6-in. How. H.E.	432,620	30,196
Chem.	33,882	2,412
60-pdr. H.E.	36,719	1,711
S.	67,127	2,067
Chem.	7,139	274
4·5-in. H.E.	224,933	6,097
Chem.	11,631	256
Smoke	17,560	386
4-in. Gun	8,222	178
18-pdr. Gun H.E.	268,052	3,778
S.	558,374	4,304
Chem.	11,224	168
Smoke	1,989	28
A.Z.	69	1
A.A.	3,312	46
3-in. H.E.	21,120	275
S.	4,683	28
13-pdr. Gun H.E.	30,095	391
S.	31,600	370
6-pdr. C.P.	15,500	108
1·59-in.	11,750	47
37-mm.	9,486	37
Total	2,027,508	66,669

[1] Prices for Canadian shell in October, 1916 :—

	£	s.	d.
18-pdr. shrapnel complete rounds	2	11	0
18-pdr. H.E. (old quotation, no contracts having been placed in 1916)	0	14	7
4·5-in.	1	11	8
60-pdr.	2	4	2
6-in.	3	2	6
8-in. } for initial orders including amortisation of plant	8	8	9
9·2-in. } for initial orders including amortisation of plant	11	14	2

[2] Memo. by Mr. Brand, 14 October, 1916.

[3] For details, *see* Vol. II, Part IV.

The output of empty shell from the outbreak of war to the end of 1918 is summarised in Appendix III, which shows a total production of 258,442,000 shell, of which 36·9 per cent. were supplied from the United States, Canada, and India, and the remainder was obtained in the following percentages from home sources :—

	Light.	Medium.	Heavy.	Very Heavy.	Total.
Ordnance Factories	4·5	3·0	·04	·3	3·4
National Shell Factories ..	12·5	16·0	8·0	2·1	12·3
National Projectile Factories ..	1·6	18·3	37·0	47·7	12·4
Co-operative Groups	30·1	29·7	16·9	6·2	27·3
Direct Contractors	51·3	33·0	38·0	43·7	44·6

CHAPTER IV.

THE CONTROL OF FACTORY EQUIPMENT AND MANAGEMENT.

I. Introductory: the Growth of Government Control.

The period 1915–1918 was marked by an unprecedented growth of the control of industry by the State,[1] which is illustrated by the work of the Gun Ammunitions Department in this respect, though the very scale of the effort makes a detailed review impossible.

Centralised control involved the balancing and standardisation of plant, the spread of approved manufacturing methods, the comparison of costs of production in terms of money, man-power and material, the comparison of costs of management and the development of proper store-keeping and accounting systems. Factories, both individually and as productive groups, were subject to the control of the Ministry in all questions of principle and in many of detail. The general routine of manufacture was left to the managements of the separate factories, but advice, and if necessary, rulings were given as to the best method of performing important operations with a view to efficiency and economy. This tended to break down trade jealousies and rivalries, and to raise the general standard of shell production to the level of expert firms. Many curious examples might be given of the importance of this pooling of shell-making experience, from which it appears that even the aristocracy of shell manufacture—the great armament firms—benefited by their contact with competitors who had come recently into the field, and who were not hampered by allegiance to traditional methods, which were only possible at a time of high prices, small output and limited competition.

As time went on the Ministry controlled the supply of capital and labour, of machinery, raw materials and components, more and more effectively. The rate of output, the nature and design of shell produced, the class of machinery ordered, the transfer of machinery from one factory to another, all these questions were considered in the light of the national needs, to which the profit and convenience of particular factories were subordinated. The same wide view was taken of labour questions, and managers who wished to offer higher wages or special inducements to labour were compelled to refrain from action which might endanger the unstable equilibrium of the labour situation as a whole. The financial control of the Ministry extended from considering large schemes of capital expenditure down to detailed day to day purchases of stores,[2] and together with this financial control, the Department exercised a control of the supply of machinery so complete that not even a new lathe could be ordered without its sanction. In short, the Ministry extended its control

[1] *See* Vol. VIII, Part I.

[2] *See* below, Chap. VI.

until it became general manager-in-chief of all the shell factories, though its relations with individual factories naturally varied according to the nature of the productive group to which each belonged.

In its control of the shell factories the Ministry had three aims in view—to speed up output, reduce costs of production, and economise raw material. These aims went hand in hand from the beginning, but, broadly speaking, output was the predominant motive in 1916, and reduction of costs in 1917, while in 1918 economy of material became the vital factor of the situation.

II. Progress Reports.

Historically, the first object of the Ministry was to provide guns and gun ammunition with all possible speed, and the evolution of an elaborate progress report system, one of the first achievements of the Gun Ammunition Department, has already been described.[1]

During 1916 and 1917 this system was maintained and developed. A progress report dealing with each of the National Projectile Factories was prepared every week, and any questions of importance arising out of it were considered by the N.P.F. Committee. The theory of the report was that it should record the chief difficulties that delayed production, together with the steps taken to overcome them. As will be seen, the report was a useful barometer for recording the general position and immediate prospects of the factories. Among the special difficulties mentioned in these reports in 1916 were shortage of labour, material, components, and gauges, disturbances caused by air raids, diminution of output owing to the fatigue of the workers and the hot weather, the effect of the holidays, congestion of traffic, which delayed the delivery of steel, and the faulty character of some of the American steel supplied by the Ministry.[2]

Where the progress report revealed special difficulties, representatives of the Gun Ammunition Department went from factory to factory to investigate causes of delay and suggest remedies. Mr. Fowler's visits to investigate the causes of delay at the Dudley, Nottingham and Hackney Marshes Projectile Factories, the Rees Roturbo Factory at Ponders' End, and the Du Cros factory,[3] during the week ending 19 August, 1916, may be taken as typical of many other visits. At Dudley there was serious trouble, the output of 60-pdr. shrapnel being held up by improper working in the forging shop. A practical metallurgist was therefore put into the factory to assist the management and the shop was shut down for six days to allow a stock of 60-pdr. forgings to accumulate, and prevent labour troubles due to shortage of work. The output of 6-in. shell at the same factory was delayed by the difficulty of replacing the machines lost in ss. "Cymric." At Hackney Marshes delay was due to shortage of machines for the last two units, shortage of machine tools, trouble with copper bands and difficulties with the Inspection Department, which insisted on

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[1] *See* above, pp. 15–16.

[2] N.P.F. Committee Minutes, August–December, 1916.

[3] D.D.G.(A.) 23884.

shell from different sources, or with various components, being bonded in separate lots. The chief difficulties at Nottingham were the shortage of steel billets for 9·2-in. shell and the unsatisfactory forgings supplied from the United States for 6-in. shell. Defective forgings and non-delivery of tools were the limiting factors at the Du Cros and Ponders End factories respectively, and arrangements were made to remove the one by a change of work and the other by representations to the Machine Tool Department.

Some of the factories were only too ready to depend on the Ministry, and expected to be helped out of all their difficulties. They constantly sent urgent telegrams asking the Department to put pressure upon firms who were supplying them with machinery or metals, with forgings, components and so on. In their eyes comparatively trifling delays were occasions for asking the Ministry to use its powers under the Defence of the Realm Act. Thus, one firm in urgent need of a second-hand locomotive and finding the owners "awkward as to price," asked the Ministry to "commandeer the engine forthwith for the new factory," but their enthusiasm was rather damped by the reply "the Ministry cannot regard this as a case for requisitioning, under the Defence of the Realm Act."[1] The Ministry refused many similar appeals, and followed the sound policy of invoking the Defence of the Realm Act as seldom as possible. It was, however, in a position to exert very strong pressure by less drastic means, and letters or telegrams from the Ministry asking firms to hasten the delivery of goods required by the shell factories were much more effective than the most urgent reminders from the factories.[2]

III. Control of Manufacturing Methods.

A resident engineer watched the technical side of production on behalf of the Ministry in each of the National Projectile Factories. The Area Superintendent Engineer gave technical advice, when required, to National Shell Factories and contractors, and reported on the suitability of various forms of factories to undertake the manufacture of shell or components. Representatives of the Small Tools Section were stationed in all the National Projectile Factories from May, 1916, until the end of the year, when, their work being done, they were withdrawn. These representatives made such forecasts as were possible of the very complicated requirements for small tools, gave expert help to the factories and persuaded them to make proper use of the tools available.[3]

There can be no doubt that this centralised control led to a great improvement in manufacturing methods. Trade jealousies and secrecies were swept away. At intervals, conferences of works managers of national and assisted factories making the same class of shell were held, at which useful information on technical points was circulated.[4] Methods found successful in one factory were

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[1] 5 September, 1916 (D.D.G.(A.) 23010).
[2] *e.g.*, D.D.G.(A.) 2886, 7373, 8285, 9079, 9245, 9403.
[3] N.P.F. Committee Minutes, 17 August.
[4] *e.g.*, the conference on 4·5-in. shell at Bradford, July, 1916.

recommended for general adoption, and new methods were investigated and if desirable introduced, *e.g.*, the method of cutting off bars by means of oxyacetylene nicking. Again, the question whether shell noses should be manufactured from forgings or machined from bar, was fully investigated. There was some difference of opinion on the point. The Production Branch was convinced that the former method produced noses of an inferior quality, with a high proportion of scrap, and that it had a destructive effect upon the machines. The Raw Materials Branch, however, favoured this method, owing to the saving of steel. Another important discussion centred on the proposal that 18-pdr. H.E. shell should be manufactured from forgings instead of steel bar;[1] steel would be saved, but the cost of manufacture would be higher.

The practical value of the accumulation of shell-making experience by the Ministry may be illustrated by referring to one or two of the cases in which it was able to give useful advice even to the armament firms, who had previously monopolised shell-making technique. Messrs. Vickers' Lancaster factory had very great difficulty in forging American steel, which the management ascribed to faulty material, but as it had similar difficulty with steel from well-known British firms, the Ministry thought that the fault was rather in the method than the material, and by testing and analysis, found that the failure was due to bad methods of forging, which it took steps to correct.[2] Bad forging methods were also discovered at Hackney Marshes, and at Dudley, where there was much delay in producing satisfactory forgings, the trouble was found to be due to improper testing.[3] Birtley had considerable forging difficulties at first, and in order to prevent difficulties with the Belgian management, emergency supplies of satisfactory forgings were forwarded to the factory by the Ministry.[4] Cases of wasteful use of plant were also discovered, as when one armament firm was found to be using 75 Libby lathes for the manufacture of nose bushes.[5]

IV. Organisation of Factory Statistics.

Proper records of machining times were essential to efficient management. The factories were urged to record the output of each machine, and it was desired that the records should be of such a nature that the foremen should be able to detect failures to obtain the maximum output for each machine on each operation, and trace the failure either to the machine or the worker with a view to getting the matter remedied.

Progress systems were set up at each of the national factories, but as some of the systems were unsatisfactory, a draft of the best progress system actually in existence at the National Projectile Factories was drawn up for general adoption (August, 1916).

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[1] D.A.O. Committee Minutes, 6 October, 1916; D.D.G.(A.) 13168.
[2] D.D.G.(A.) 26011/0.
[3] HIST. REC./H/1122.4/1, 5.
[4] October, 1916. (HIST. REC./H/1122.4/3).
[5] Shell and Components Committee Minutes, 30 April, 1917.

Efforts were also made to profit by the best American practice, and a report on the manufacture of 9·2-in. shell in America, which laid great stress on questions of organisation and administration, was printed by order of the N.P.F. Committee[1] and circulated to all shell factories. It was an essay on the thesis that production is affected more by the organisation than by the machines provided. The adoption of piece work or bonus system was believed to be one of the main elements in the success of American methods. The report gave details of the method in which responsibility for overlooking the work was divided, of the "hospital shop" system for treating slightly defective shell and avoiding stoppage of the even flow of work through the shops, and emphasised the importance of ample tool-room accommodation, which would allow each workman to have at least one spare set of the tools he used. The American method of handling shell in the shops and American machining methods were also reported on, and the times for machining and handling were given.

V. Control of Store-keeping and Accounting Methods.

As has been seen, a complete system of cost accounting had been introduced in all the national factories in the autumn of 1915, but, while some of the factories were able to produce their costs with the utmost regularity, others were continually falling into arrears.

The D.A.O. Executive Committee kept a watchful eye on the financial proceedings of the Boards of Management. Representatives of the Finance Department visited the National Shell Factories at intervals to audit stores, records and stocks, and suggest improvements in auditing and account keeping, and special help had to be given to the Boards of Management at Liverpool and Birmingham, the accounts of the latter especially being in a very unsatisfactory state. The difficulty and delay in obtaining complete cost returns from some of the National Projectile Factories was due to lack of foresight as to the clerical staff, office accommodation, and stores accommodation required. In the factories which had secured reliable men from the staff of the managing firms, the account and store-keeping arrangements were better organised.[2]

VI. Control of Factory Management and Organisation.

The firms who managed the National Projectile Factories were experienced engineering firms, who required comparatively little technical assistance. It did not always follow, however, that their organising capacity was equal to their technical experience, and the factories had not been at work long before the Ministry found itself obliged to undertake large schemes of reorganisation, and to introduce more modern methods of supervision. In July, 1916, for instance, reorganisation schemes were in progress at Templeborough, Hackney Marshes and Cardonald, and in August the N.P.F. Committee came

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[1] Articles in *Ministry of Munitions Journal*, December, 1916, January, 1917.
[2] N.P.F. Committee Minutes, 31 August, 7 September.

to the conclusion that the stores systems of the factories were not properly organised, that their requisitioning of small tools was unsatisfactory, and that in one case at least the buying arrangements were liable to be sacrificed in the interests of the managing firm's own principal works.

An extremely unsatisfactory state of affairs existed at Lancaster. The arrangements with regard to small tools were quite inadequate, the machinery provided was not being used to the best advantage, and there was much untidiness and confusion in the shops.[1] As a result a new manager was appointed, who was much more successful.[2] Hackney Marshes was a factory which, with an excellent start, had made very disappointing progress,[3] its difficulties being due in the opinion of the Ministry to bad management and organisation. After various unsuccessful attempts to improve both, the factory was finally taken over by the Ministry, in August, 1917. Dudley also went through a difficult period in the summer of 1916, when, owing to bad management and general disorganisation, it became known locally as the "National Scrap Factory." The factory was closed for reorganisation and a great improvement followed.

There were similar difficulties with Boards of Management. The Birmingham National Shell Factory made very slow progress, and the Ministry had made attempts at reorganisation in the autumn of 1915.[4] On 15 May, 1916, the Director of Area Organisation stated that he had just received a very serious report with regard to the Birmingham Board, which had arisen, he thought, out of the reprehensible practice of placing large sums of money at the disposal of Boards of Management. A sum of £750,000 had been spent, and deliveries were much in arrears. The Board was paying 3s. 6d. to sub-contractors for bottling shell, an operation costing less than 9d. at other National Shell Factories. The Board's method of buying shell forgings had been extraordinary, and there was no attempt to co-operate with the Area Office, contracts having been placed and plant ordered with too little care. No costs whatever had been received from Birmingham by 21 May, but it was anticipated that they would be high. A special investigation showed that the accounts of the Board of Management were in a very unsatisfactory state. Changes were made in the personnel and a competent accountant was sent down to help the board in its work.[5] Later on, difficulties again arose over orders placed by the Board for 4·5-in. forgings at 18s. 6d. each, though a standard price of 13s. 6d. had been fixed by the Ministry. The D.A.O. Committee, therefore, recommended that no price above the standard price paid by the Ministry should be sanctioned.[6]

In order to weed out inefficient firms the Boards of Management were asked to prepare a list of firms who were unable, through defective equipment or organisation, to carry out their contracts satisfactorily, and no further contracts were to be placed with such firms (6 October).

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[1] C.G.M. 29782.
[2] C.G.M. 29782.
[3] HIST. REC./H/1122.4/4.
[4] HIST. REC./H/1121.24/6, pp. 29–35.
[5] In several other cases the Ministry made changes in the personnel of Boards of Management.
[6] D.A.O. Committee Minutes, 3 November, 1916.

Firms were to be considered inefficient who were not prepared to employ 85 per cent. of women or boys on smaller shell, or not in a position to produce 100 18-pdr. shell per week or an equivalent of larger shell, or unable to produce shell complete up to the banding process.

When the management alone was at fault, the committee advocated improving it by a reliable follow-up system rather than by withdrawing contracts and removing the tools. Inefficient managers were removed and new managers appointed.[1]

From the outset the relations between the Ministry and the Metropolitan Munitions Committee were stormy.[2] The latter was jealous of any interference and made claims which the Department was not prepared to grant. Serious difficulties arose in the autumn of 1915, when the Committee was criticised for its carelessness in placing contracts for ball grenades without a cancellation clause, involving loss when the demand for the grenades ceased. Again, the Committee's administrative organisation, which consisted of a head office and sixteen district centres, was complicated and expensive, costing about £35,000 a year. The Committee argued that it had succeeded in placing a number of contracts below the maximum prices authorised by the Ministry, thus saving £160,771. Some improvement followed on the centralisation advocated by the Ministry, but the administrative expenses remained high. By September, 1917, the Committee's expenditure amounted to £123,272 16s. 3d., more than £1·07 per cent. on the value of the contracts placed, which was a higher percentage than that of any other committee. As the reduction of the shell programme would reduce the volume of contracts placed and make the cost of administration still heavier in proportion, it was decided (8 May, 1918) that the Committee was to be dissolved, all new contracts being placed by the Ministry direct after 1 July.

At Rochdale several members of the Board of Management belonged to firms who had commercial dealings with the factory they controlled. The whole of the plant for the factory had been made by members of the Board, and there was a most undesirable conflict of interests, which was ended by the general control of the factory being transferred to the Area Engineer (July, 1916). He found that the factory needed a thorough reorganisation. There was no inspection until the shell was practically finished, and consequently very heavy rejections—1,000 out of 1,500. There was no rectifying plant, the correct speeds for machine tools were unknown, the feeds were of an out-of-date type, and the operation times were three times as long as the average times.[3]

There was one case at least of a factory being so badly managed that its output was negligible, while in spite of an advance of money by the Ministry, secured by debentures, it got into financial difficulties.[4] The factory was taken over by the Ministry under the Defence of the

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[1] *e.g.*, Carlisle, Bury, Newport. A joint manager was also appointed for the three National Shell Factories in North Wales.

[2] For a detailed account of the Committee's work, *see* Hist. Rec./H/1121.27/1.

[3] D.A.O./2/58.

[4] 94/London/16; 15/Muns/2158, 2711; Hist. Rec./H/1121.27/1; D.A.O. Committee Minutes, 16 June (11).

Realm Act, and the Department subsequently ran it with considerable success, working up its output to 4,000 4·5-in. H.E. shell per week within six months.[1]

The Department occasionally had to take action under Regulations 42 D and 45 L under the Defence of the Realm Acts, which gave it power to prosecute any person, whether contractor or workman, who "wilfully or by gross negligence manufactured or assisted in manufacturing fraudulent or defective stores which might endanger the lives of those using them."[2]

Before the introduction of these regulations it was possible to bring an action against the contractor in a civil court for breach of contract, but there was no remedy against the workman unless there was evidence of a conspiracy. This made prosecution practically impossible. Regulation 42 D, was aimed at cases of suspected sabotage, but was found useful in a number of less serious cases, *e.g.*, in the case of Kupfenberg who was prosecuted for fraudulently stamping defective components with the Government mark. One engineering firm was found guilty of plugging holes in defective base plates, and as a result the manager of the firm was sentenced to a term of imprisonment. Following upon this prosecution, a quantity of 3-in. Stokes bombs were returned to Watford No. 2 Filling Factory to have their base plates examined, when it was found that a considerable number of bombs had holes similarly plugged, these bombs being manufactured by at least a dozen different firms, numbering among them some of the most important engineering firms in the country. Fortunately the majority of the cases of plugging reported were probably harmless, but there were also cases of malpractice, for instance the cases where lead plugs with steel centres were supplied, and where heads were fitted instead of bases, which should certainly have been detected at inspection.[3]

Regulation 45 L, was issued to meet certain serious instances of defrauding the Inspection Department by tampering with test pieces, and the experience of the Ministry suggested that the substance of these regulations might usefully form part of permanent legislation.

VII. Supply and Transfer of Machinery.

The original arrangements for supplying the National Projectile and Shell Factories with machine tools, through the Machine Tool Department, assisted by the Area Engineers, have already been described.[4] By the middle of 1916 the bulk of the machine tools required had already been bought, but all new orders for machinery had to be submitted to the Ministry before they were placed. The practice in May, 1916, was that the orders for the machinery required by the National Projectile Factories were sent to the Gun Ammunition Department, approved if they were thought to be necessary and reasonable in price, and certified by the Machine Tool Department. It was proposed that all the orders approved should be forwarded to the

[1] HIST. REC./R/400/42.
[2] HIST. REC./R/221/21.
[3] T.W. 9674/36.
[4] *See* above, pp. 31, 32.

Finance Department of the Ministry for sanction, and that a list of the plant so approved should be kept at the factories,[1] but this arrangement was not strictly observed.

The control of the Ministry tightened up as time went on, and this extension of control, though very unpopular with the managing firms,[2] as it limited their freedom of choice and obliged them to accept unfamiliar British machines, or, when necessary, American machines, ultimately improved the state of the machine tool market by minimising the competition for machinery among the great armament firms. Every application to instal new machinery was considered from two aspects—its desirability from the technical point of view, on which the Superintending Engineer was frequently consulted, and its justification from the financial standpoint,[3] and approval was subject to the provision that tenders should be invited and the lowest tender accepted.[4] This condition was waived in special circumstances, as for instance, when a factory wished to buy from a firm which had already supplied a number of satisfactory machines, in which case it was more economical to have them all of the same type.[5]

National Projectile Factories had priority over National Shell Factories with regard to the supply of machinery and of small tools, and the D.A.O. Committee worked on the general principle that no new machinery was to be sanctioned for schemes under its control unless under exceptional circumstances. Wherever possible existing facilities were to be utilised, and this committee was therefore specially active in arranging for transfers of machinery from one factory to another.[6] A request for new machinery from a Board of Management had to be approved by the Superintending Engineer, and by the Machine Tool Department before being referred to the D.A.O. Committee. The committee constantly impressed the Boards and their contractors with the necessity of limiting their demands, and urged them to buy machinery second-hand wherever possible.[7]

VIII. Balancing and Standardisation of Plant.

The Ministry viewed the National Projectile Factories as a single productive group, and gave constant attention to balancing their plant by transfer of machinery or otherwise, in order to attain the maximum output from the group. On 6 July, the N.P.F. Committee made a general ruling on this question of balancing of plant. It was decided that the factories should be visited periodically by inspectors from the Machine Tool Department, and the Production Branch, who would report on machines that were superfluous or lacking and recommend transfer. It was understood that the transfer would be a continuous process which would go on apart from these periodical visits. Cases

[1] N.P.F. Committee Minutes, 29 May, 1916.
[2] *Ibid.*, 24 August, 1916; D.D.G.(A.) 2917.
[3] *e.g.*, shell elevators at Mile End, and transformers at Cardonald; N.P.F. Committee Minutes (324). [4] *Ibid.*
[5] N.P.F. Committee Minutes, 30 November, 1916 (330).
[6] *See* below, p. 77.
[7] *e.g.*, D.A.O. Committee Minutes, 10 October.

where part of the machinery was reported to be idle were enquired into and arrangements made for transfer to another factory.[1] Special arrangements were occasionally made to balance the plant by the loan of special machines from a factory which could spare them.[2] Special efforts were made to improve the balancing of plant in the National Projectile Factories in order to increase their output to meet the gun ammunition programme of October, 1916.[3]

The termination of the 18-pdr. H.E. contracts left a large amount of machinery in National Shell Factories standing idle in June, 1916, and at the same time very large demands for new machinery were being put forward by the Mechanical Transport Department, the Trench Warfare Supply Department and the Aircraft Production Department. As a result of a conference between representatives of these departments, and of the Area Organisation and Machine Tool Departments, the Boards of Management were instructed to make a list of the surplus machine tools, small tools and gauges, which were to be sold by the Machine Tool Department to firms requiring them.

When a balancing-up scheme so ambitious as to amount practically to the provision of a new plant came before it, the D.A.O. Committee deferred its sanction (17 November). Wherever possible balancing-up applications were to be met by supplying second-hand tools, even although this would entail some delay. Later on, at the end of 1916, many applications were received from Boards of Management for tools to balance plants for the manufacture of 18-pdr., and 4·5-in. shell, and in view of the promise given by the Minister to the contractors, it was found necessary to sanction some of these applications, confining the sanction, however, to those proposals that provided for a relatively large increase of output by the addition of but few tools.

By the beginning of 1917, it was clear that there was quite enough shell-making machinery in the country to meet all probable demands, and that the necessary margin for expansion of output could be obtained by making full use of such existing machines as were only running on day shifts. The Shell and Components Committee therefore decided to investigate fully any application for machine tools for shell-making, and only to sanction such applications when a clear case was made out for their necessity.[4]

The reduction of the gun ammunition programme and the transfer of surplus 8-in. and 9-in. shell-making capacity to gun repair has already been dealt with.[5]

In 1916 instructions had been given that inventories should be prepared of all plant and machinery belonging to the Ministry whether in national factories or on the premises of assisted contractors. There had been much delay in carrying out this instruction, and it was not until 1918 that the matter was put upon a sound footing by Mr. Webster Jenkinson, the Controller of Factory Accounts, the preparation of the

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[1] *e.g.*, N.P.F. Committee Minutes, 6 July, 1916.

[2] *Ibid.*, 8 June, 15 June, 14 September, 16 November, 23 November, 30 November, 1916.

[3] *Ibid.*

[4] Shell and Components Committee Minutes, 5 February, 1917 (39).

[5] *See* above, p. 55.

inventories being under the supervision of the Department of Engineering. The inventories were to be prepared in the first place from the invoices and financial books, the price of the machine and the date at which it was installed being recorded. All plant and machinery belonging to the Ministry was to be marked with the Ministry code letters and numbers. All inventories were to be kept up to date, the factory or contractor being required to keep a register of plant and record any transfer of or alterations or additions to plant. A separate inventory was required for each contract.[1]

[1] *See* Memorandum on the Preparation of Inventories of Machinery and Plant (Copy in Hist. Rec./R./430/3.)

CHAPTER V.

THE DISTRIBUTION OF RAW MATERIALS AND METAL COMPONENTS.

I. Modification in the Specification of Steel for High Explosive Shell.

(*a*) Percentage of Sulphur and Phosphorus.

During the first year of the war, shell contractors had obtained steel from the makers who usually supplied them without the intervention of the Government. The specifications which determined the composition of shell steel were rigid, and only two or three firms, whose combined production amounted to about 5,000 tons a week, could produce steel of the quality required. The growing demand for steel for shell necessitated a departure from the original specification, the percentage of sulphur and phosphorus allowed in steel for high explosive shell being raised by successive steps from ·025 per cent., at which it stood when the war broke out, to ·08 per cent. Since a high percentage of sulphur renders steel brittle when hot, and a high percentage of phosphorus makes it brittle when cold, the relaxation of the limits was only conceded owing to the exigencies of supply.

By June, 1915, the limit had already been relaxed to ·05 per cent. of sulphur and phosphorus for land service shell and to ·04 for naval shell, the following being the chemical composition laid down in the specification[1] :—

	Minm.	*Maxm.*
Carbon	—	0·55 per cent.
Nickel	—	0· 5 ,,
Silicon	—	0· 3 ,,
Manganese	·04	1· 0 ,,
Sulphur	—	0·05 ,,
Phosphorus	—	0·05 ,,
Copper	—	0· 1 ,,

A report submitted to the Minister by Dr. J. E. Stead (about 9 August, 1915)[2] had laid stress upon the fact that the British specification for shell steel appeared to be unnecessarily stringent, since the enemy was using steel to kill the Allies which the British authorities considered unfit to use against the Germans. Dr. Stead thought the raising of the percentage of sulphur and phosphorus would enable the Cleveland ore to be used. The Director of Raw Materials emphasised the importance of raising the sulphur and phosphorus limit to ·06 per cent. (20 August, 1915).[3] Experts were of opinion that this small increase would have no serious effect upon the quality of the

[1] D.G.M.D./S/168.
[2] M.W. 28144; M.W. 11117/2; D.G.M.D./S/245.
[3] C.R. 2369.

steel, while it would enable many makers to begin manufacturing shell steel, who could not then do so. The Ministry asked the War Office to sanction this raising of the limit on 26 August, pointing out that it was absolutely necessary if sufficient steel was to be obtained to carry out the proposed shell programme. There were considerable quantities of East Coast, West Coast and Scotch hematite pig iron which contained about ·05 per cent. sulphur and phosphorus, and steel made from such iron would contain about ·06 per cent. sulphur and phosphorus. Further, the output of basic hearth furnaces would be reduced by about 20 per cent. if the lower limit were insisted upon. There was also a possibility of a shortage of Swedish pig iron, which might have to be replaced by low phosphorus and sulphur West Coast iron. At the same time the Admiralty was asked to raise its limit for shell steel from ·04 to ·05 per cent.

The War Office replied (17 September) sanctioning the increase to ·06 per cent., provided the total percentage of sulphur and phosphorus did not exceed ·1, but the Ministry pointed out that this concession was insufficient. The shell steel orders already placed amounted, including 650,000 tons for the French, to 1,857,000 tons, which was equivalent to 35,700 tons per week of finished steel. If the Army Council adhered to its decision the amount of steel produced would certainly fall short of requirements, as even if the ·06 limit was allowed the steel makers estimated that only about 32,000 tons of finished shell steel would be obtainable. The Ministry also criticised the Army Council's suggestion that the percentage of sulphur and phosphorus might be allowed to vary, provided the combined percentage did not exceed ·1. "A quite appreciable increase in sulphur may have far less effect than an equivalent increase in phosphorus and to assume that both act in the same direction is contrary to all experience."

The Army Council admitted the force of these arguments, and on 1 October sanctioned a maximum limit of ·06 per cent. of sulphur and ·06 per cent. of phosphorus—a decision which was welcome owing to the fact that stocks of low sulphur and phosphorus iron were very low. The Admiralty met the Ministry in conference on 2 September, and in view of the small amount of steel involved—about 90,000 tons—the Ministry agreed to the maintenance of the Admiralty standard of ·04 per cent.[1]

On 14 October, however, the Army Council announced that it has reconsidered its decision, and that until it was furnished with further information as to the absolute necessity of extending the limits of phosphorus and sulphur, the use of steel containing sulphur and phosphorus up to a maximum of ·06 per cent. of each would only be permitted for land service shell of 5 inches and below. The Ministry pointed out (29 October) that orders for shell steel for 1916 had already been placed on the ·06 per cent. basis, and that unless the limit of ·06 per cent. were permitted the supply of steel would fall short of the demand by 17,000 tons a week. Moreover, representatives of the French steel makers had met the British steel makers in conference

[1] C.R. 2369.

and had agreed to a limit of ·08 per cent., provided the steel passed the proper mechanical tests. On the request of the Army Council, the Ministry produced figures showing that only about 8,000 tons a week could be obtained with the ·05 per cent. limits (1 December). On 11 December the use of steel with a maximum percentage of ·06 of sulphur and ·06 of phosphorus was approved by the Ordnance Board and the Design Department for all natures of high explosive shell.[1]

On 10 January, 1916, Dr. Stead wrote another letter to Mr. Lloyd George urging that the limit should be raised to at least ·07 per cent., the amount found in one of the shell fragments sent into the East Coast from the German ships. He had submitted shell produced from material barred by the existing specifications to certain tests and found that they stood up to shocks much more severe than those in the gun itself. After further investigation, and after the chief armament firms had been asked for their opinion, the Ordnance Committee recommended that the limit should be raised to ·07 per cent. sulphur and phosphorus for all sizes of high explosive shell.

Nearly a year later (February, 1917), the maximum permitted was again raised, the percentage of sulphur and phosphorus being increased to ·08 per cent. for English made steel.[2]

Steel specifications originally stipulated that only acid steel made by the open hearth process should be used. On 27 August, 1915, Mr. West asked that the use of acid bessemer steel should be sanctioned for high explosive shell,[3] but it was not until 23 November that the Director of Artillery sanctioned this concession, confining it at the same time to steel supplied by six firms: Messrs. Henry Bessemer, Brown Bayley, Cammell Laird, Samuel Fox, Steel Peech & Tozer, and the Workington Iron and Steel Company. Top pouring of the ingots was to be insisted on and occasional inspection made of the process.[4]

(b) NORMALISING SHELL STEEL.

On 30 December, 1915, Mr. Peech reported that very good results had been obtained by normalising samples from a consignment of steel bars from Australia. This normalising produced a considerable change of structure and the steel gave much better results in the mechanical tests for yield point and elongation. Steel bar was normalised by being heated up in a continuous furnace to a temperature of 850 deg. centigrade and allowed to remain at this temperature for 15–20 minutes, being afterwards removed and placed on gantries to cool. The bars were not to be allowed to touch each other while being cooled, and the gantries had to be under cover.[5]

The Ordnance Committee had already asked whether all steel for high explosive shell could be normalised (19 December, 1915) but Mr. West stated that it was impossible to contemplate the normalising

[1] C.R. 2369; D.G.M.D./S/168. The concession was not extended to America as Messrs. J. P. Morgan thought it would have no material bearing on the steel situation. Cables L. 18124, N.Y. 19483.

[2] D.G.M.D./S/245. [3] D.D.G.(A.) 2834. [4] D.G.M.D./S/12.

[5] Note by A.M.2, 8 February, 1916 (D.G.M.D./S/152).

of all high explosive shell steel. He thought normalising after forging unnecessary and the Chief Superintendent of the Ordnance Factories agreed with this, but the case of shell machined from bar was different, and arrangements were being made in some factories for the bar to be normalised.[1]

The proposed normalising of steel bar was not then insisted on, as the Inspection Department stated on 13 March, 1916, that it was unnecessary, except in cases where the bars had been irregularly cooled after rolling and were too hard. Shell forgings which had been chilled by being dropped into water or wetted while hot might also require normalising, but the practice was seldom necessary if care was exercised during the cooling of the forgings.[2]

In the autumn of 1916, however, a general direction that steel bar from which 18-pdr. H.E. shell was to be made should be normalised was issued by the Design Department. This instruction involved considerable risk from the supply point of view ; it meant that 18-pdr. plants throughout the country would have to stop, since normalising plant could not be obtained and put into operation in time to treat the January deliveries of steel.[3]

II. Distribution of Shell Steel Forgings.

As has been seen, when the schemes for National Shell Factories were being discussed in the spring of 1915, the Armaments Output Committee had undertaken a certain responsibility for the supply of steel, and when the Ministry was formed this responsibility was developed, and the Raw Materials Branch of the Gun Ammunition Department undertook to buy shell steel from the makers at fixed prices varying from £15 per ton uncut for 18-pdr. steel, to £18 10s. for 12-in. steel and £17 for shrapnel steel. Another branch distributed this steel or shell forgings to national factories and Board of Management contractors, the growing shortage of steel bringing direct contractors into this scheme from the middle of 1916 onwards. With the exception of the National Projectile Factories and the armament firms, shell contractors were unable to make shell forgings. The Ministry, therefore, gave financial assistance to several forgemasters to enable them to extend their plant, and constructed and worked two new forges. In addition, large orders for forgings were given in the United States and Canada.

Owing to inexperience, the percentage of unsatisfactory forgings produced was at first very high, sometimes as high as 20 per cent.[4] The Shell Manufacture Department met this difficulty by training a staff of inspectors to help inexperienced forgemasters, with the result that the percentage of rejects was reduced to about 2 per cent. This compared very favourably with the results obtained by the armament

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[1] 22 December (C.R. 2369). [2] D.G.M.D./S/311.
[3] D.A.O. Committee Minutes, 10 November, 1916.
[4] Large shipments of Canadian 18-pdr. shrapnel forgings had to be condemned in March, 1916, as they failed to pass the tensile test. Some of them were heat treated with good results. (Printed) *Weekly Report*, No. 34, I, No. 39, III (18.3.16, 29.4.16).

firms. Several of the National Projectile Factories in spite of their experienced management, had at first great difficulty in producing satisfactory forgings, and the improvements effected by the Ministry have been considered elsewhere.[1]

III. The Growing Shortage of Shell Steel.

The shortage of shell steel and forgings first became apparent in March and April, 1916,[2] though it did not become acute until about August, 1916. From that time onwards the available supplies of raw material had to be distributed with the utmost caution, the general principle followed being to distribute steel first to contractors making shell for which there was an urgent demand from the Field. Thus during 1916, when supplies of heavy shell were of the utmost importance, the National Projectile Factories enjoyed a priority over the National Shell Factories and Board of Management contractors, which lasted until January, 1917, when light shell was in great demand.[3] On 22 January, 1917, the Shell and Components Committee laid down the general rule that where there was a shortage of steel or other raw material, all classes of producers—national factories, Board of Management contractors, direct contractors and assisted direct contractors—should share alike, unless the committee decided, as a matter of policy, to differentiate in favour of a particular class.[4] Thus the National Projectile Factories lost the priority they had long enjoyed.

The distribution of steel had to be done with great care to avoid penalising the various factories and contractors, and the machinery adopted may be briefly outlined. The allocation to Board of Management contractors was at first reached by agreement between the Director of Area Organisation and the Shell Manufacture Department. Later on, in August, owing to the creation of a Raw Materials Department, independent of the Shell Manufacture Department, an allocation of steel covering the total requirements of all contractors, National Projectile and Shell Factories making the larger natures of shell was prepared by the Shell Manufacture Department,[5] while the total amount of steel and steel forgings available for shell factories administered under the D.A.O. Committee was distributed among those factories in accordance with an allocation prepared by the Area Organisation Department.[6] Weekly returns of the forgings and steel supplied to Boards of Management from 28 October, 1916, onwards were presented to the D.A.O. Committee. These returns showed that the supply fell far short of the requirements, particularly, with regard to forgings for 4·5-in. and 6-in. shell, and there were serious difficulties with contractors in consequence.

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[1] *See* above, p. 71.
[2] (Printed) *Weekly Report*, No. 34, VI (18.3.16).
[3] Shell and Components Committee Minutes, 23 January, 1917.
[4] *Ibid.*, 22 January, 1917.
[5] D.A.O. Committee Minutes, 18 August.
[6] *Ibid.*, 6 October.

On 1 December, 1916, it was stated that it would not be possible to give Board of Management contractors more than a percentage of their requirements for the first six months of 1917 :—

	4·5-in.	18-pdr. H.E.	18-pdr. Shrapnel.
January	35 per cent.	30 per cent.	20 per cent.
February	45 ,, ,,	40 ,, ,,	30 ,, ,,
March	55 ,, ,,	55 ,, ,,	40 ,, ,,
April	60 ,, ,,	70 ,, ,,	60 ,, ,,
May	65 ,, ,,	100 ,, ,,	100 ,, ,,
June	70 ,, ,,	100 ,, ,,	100 ,, ,,

The D.A.O. Committee brought the matter to the attention of Mr. Stevenson and Mr. West, enquiring whether this was the considered policy of the Ministry, in view of the statements previously made to the contractors that every shell that could be made of these natures was required. By 15 December it had been decided that contracts for 4·5-in. shell were only to be placed for the output possible on a single shift,[1] and representatives of Boards of Management agreed to explain to their contractors that this shortage was inevitable and must be faced. In order to meet what was admitted to be a case of special hardship, the Lubbock Committee decided that contractors should bear without compensation any shortage of supplies of forgings up to 10 per cent., but that in cases where the supplies were below 90 per cent. of the requirement, 1d. should be added to the price of shell delivered in respect of each 1 per cent. that the supplies of forgings fell below 90 per cent. of the contract quantity.[2] It was hoped that this decision would allay a good deal of the soreness felt by contractors as a result of the shortage of material. This compensation was not extended to other natures of shell or to subsequent periods.

The supply of forgings for 18-pdr. shrapnel caused similar difficulties.[3]

IV. The Supply of Steel to meet the Programme of October, 1916.

The shell programme arranged in October, 1916, required 81,400 tons of steel a week, and in order to meet it, a great extension of home production was required. In September, 1916, it was estimated that the output in the United Kingdom could be raised from 24,000 to 37,000 tons a week, but that this extra output could only be obtained if labour was forthcoming immediately to start up blast furnaces, increase the output of silica and other bricks, and make extensions to steel works. The remaining 44,400 tons would have to be obtained from overseas in the form either of shells or of steel. The Advisory Committee was of the opinion that if the full shell programme was to be reached in June, 1917, the total quantity of 81,400 tons a week must be available by March[4].

The following table gives a statement of the position in September, 1916, and an estimate of the amount of steel which would probably be available by March and June, 1917.

[1] D.A.O. Committee Minutes, 15 December, 1916.
[2] Shell and Components Committee Minutes, 22 January, 1917.
[3] *Ibid.*, 22 June, 13 October, 1916. [4] A.C. 2, 148 (18 October, 1916).

WEEKLY SHELL STEEL PRODUCTION IN SEPTEMBER, 1916, AND AS ESTIMATED FOR MARCH AND JUNE, 1917.

	Sept., 1916.	March, 1917.	June, 1917.
	Tons.	*Tons.*	*Tons.*
Home Steel	21,800	29,500	37,000
U.S.A. as Shells (Works Output)	13,000	24,000	8,900
U.S.A. as Steel and Forgings (Works Output)	14,000	20,000	20,000
Canada as Steel and Forgings (Works Output)	—	10,000	10,000
Canada as Shells (Works Output)	9,200	14,500	21,800
	58,000	98,000	97,700

If these estimates were realised some 98,000 tons of shell steel would be available in March, 1917, to meet a shell programme requiring 81,400 tons, so that it appeared that steel would not be the limiting factor of the new programme. These calculations, however, depended on two uncertain factors, obtaining the labour required for the steel works extensions, and obtaining delivery of the shell steel already ordered without the interference of the Admiralty. This raised a difficult problem, which is dealt with elsewhere.[1]

As a result of negotiations between the Departments concerned, supplies for the various War Departments and the mercantile marine during the first half of 1917 were allocated in November, 1916.[2] The result was very satisfactory to the Ministry. From January to June 1917 the Ministry was allocated 1,523,000 tons for its shell programme which meant that it would obtain 1,133,000 tons, or about 43,576 tons a week of shell steel from home sources, the balance, 390,000 tons, being imported from America. This more than met the allocation of 37,000 tons a week required for the shell programme, which by this time had been reduced.[3] The Ministry was also allocated 520,000 tons of steel for French shell and 26,000 tons of steel for shell for the other Allies during the six months.

Sir Glynn West pointed out that in order to carry out the shell programme proposed in October, 1916, a month's stock of steel must be held in the country, and that there should be a month's stock at every factory. After the steel was made it took a week to break; the next week it was delivered, the next week forged, and it took two weeks more to get it through to finished shell.

The utmost economy of steel was of vital importance in view of the "unrestricted" submarine campaign that began in February, 1917, and successive reductions of the gun ammunition programme cut down the demand for shell steel from 51,000 to 40,000 tons, and finally to 30,000 tons a week. The Advisory Committee at first

[1] *See* Vol. VII, Part II.

[2] *See* Table in Supplement to Section IV. of (Printed) *Weekly Report*, No. 68 (18.11.16).

[3] *See* Appendix II.

anticipated that the reduced gun ammunition programme put forward in February, 1917, would result in a saving of about 10,000 tons of steel a week, though the effect of it would not be felt until the arrears in the steel deliveries required for shell manufacture had been made up.[1] The Minister, however, made some changes in this programme, which increased the weekly requirement for H.E. steel from 29,700 tons to 34,740 tons, and of shrapnel steel from 3,650 to 4,300 tons,[2] but a later modification (13 April) cut down the manufacture of 8-in. and 9·2-in. and reduced the amount of steel required by about 6,000 tons a week. It was hoped that a surplus of 7,000 tons a week, as compared with the March programme, and of 18,000 tons a week as compared with the October programme would be available for shipbuilding, with a possible addition of 3,000 tons a week if supplies to Italy were discontinued. This estimate, however, was not to be realised, owing to the arrears in steel for 18-pdr. and 4·5-in. shell, then urgently wanted, which had to be made up, and, at a conference with the Admiralty (30 July, 1917), the diversion of 5,000 tons of shell steel a week to ship plates was decided upon.[3] On 9 August, the War Cabinet decided that ships' plates were to have precedence of shell steel.

The following table shows the quarterly deliveries of shell steel from home manufacturers, from Canada, and the United States of America :—[4]

	Home Output.[5]				Imported.[6]		
	For Great Britain.	On Allied Account.	For Allies.[7]	Total.	U.S.A	Canada.	Total.
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*
1915 (23 Oct.–25 Dec.)	146,300	—	57,200	203,500	—	4,675	4,675
1916—							
1st Quarter ..	235,423	—	134,729	370,152	—	—	18,242
2nd „ ..	291,686	—	156,893	448,579	—	—	24,933
3rd „ ..	303,051	—	139,130	442,181	—	—	90,649
4th „ ..	320,799	—	138,938	459,737	—	—	153,203
Total ..	1,150,959	—	569,690	1,720,649	268,683	18,344	287,027
1917—							
1st Quarter ..	327,165	15,681	120,409	463,255	161,709	11,674	173,383
2nd „ ..	321,863	15,040	134,929	471,832	299,276	48,995	348,271
3rd „ ..	295,719	4,666	125,016	425,401	347,031	60,525	407,556
4th „ ..	273,444	1,529	110,761	385,734	256,196	21,981	278,177
Total ..	1,218,191	36,916	491,115	1,746,222	1,064,212	143,175	1,207,387
1918—							
1st Quarter ..	253,367	8,499	38,647	300,513	221,966	28,709	250,675
2nd „ ..	238,832	13,271	21,112	273,215	174,873	796	175,669
3rd „ ..	245,175	10,629	13,731	269,535	146,212	5,362	151,574
4th „ [8] ..	140,853	4,819	6,630	152,302	147,788	3,164	150,952
Total ..	878,227	37,218	80,120	995,565	690,839	38,031	728,870

[1] Report of Advisory Committee, 2 March, 1917 (A.C. 71).
[2] 7 March, 1917. [3] Memorandum, 30 July, 1917.
[4] Review of Munitions Output, 1914-18.
[5] Despatches from steel works to British shell makers.
[6] Arrivals at British ports.
[7] For 1915 and 1916 these figures include despatches to British shell makers for shell for Allied Governments.
[8] To 30 November, when despatches ceased.

V. Economies in Metals.

The steel shortage, as has been seen, began about the middle of 1916, and remained acute until the end of the war; but the shortage of other metals required for gun ammunition manufacture—copper, brass, and lead—did not become serious until the late autumn of 1916, when a new gun ammunition programme made largely increased demands upon the available supplies of munitions metals. A Metals and Materials Economy Committee was appointed to consider possible savings and substitutions,[1] and throughout 1917 experiments were being made with various substitutes, some of which had afterwards to be abandoned as unsatisfactory. The substitution of lighter driving bands for certain natures of shell saved about 19,000 tons of copper yearly, while another economy was the manufacture of driving bands from strip instead of rings.[2]

In order to economise brass, which was urgently needed for Admiralty and other munitions work, and which was being bought in America at a very high price, the manufacture of the No. 101 and 106 fuses in cast iron was decided upon, in October, 1916. A great saving in brass resulted, but the cost of machining these fuses was very high and great difficulty was found in rust proofing them.[3]

The Metals and Materials Economy Committee also experimented with other metal economies in shell manufacture, making the central tubes of shrapnel shell of steel or *papier maché* instead of brass, making nose-bushes of H.E. shell of cast iron,[4] making the cups for 18-pdr. and 60-pdr. shrapnel of cast iron, making primers of steel instead of brass, etc. Some of these economies were carried out during 1917. Thus, all contractors and managers of national factories were forbidden to use brass for the nose-bushes of H.E. shell after 31 March, and were instructed that either steel nose-bushes must be used, or the shell must be manufactured without nose-bushes. The latter alternative would be preferred by the Ministry, which did not intend to put itself under any obligation to supply contractors with steel nose-bushes.[5]

The change from brass to steel centre tubes in 18-pdr. shrapnel shell involved more than a mere change in material; it involved a considerable change in methods of manufacture. In the first place it was necessary to get Woolwich to relax the tolerances allowed for the centre tube, as, if the steel tube had to be made to the same limits as the brass, it would have necessitated the use of solid drawn steel tubing, which, owing to the needs of the Admiralty and the Aeronautical Supply Department, would have been quite as difficult to obtain as brass tubing. By 12 June, 1917, this difficulty had been overcome, and orders had been placed for steel centre tubes to cover the whole home manufacturing programme for 18-pdr. shell, 400,000 per week. The cast iron fuse sockets which were introduced, in order to economise

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[1] M.E.C./Gen./080.

[2] D.G.M.D./B/027; A.C./8; A.M.3 A/T/1929; Minutes of Heavy Gun Shell Committee, 4 June, 1918.

[3] A.C. 8.

[4] *Ibid.*

[5] Shell and Components Committee Minutes, 12, 19 February, 20 March, 27 June, 1917.

brass in 18-pdr. shrapnel shell, gave good results in trials,[1] but were less satisfactory in the Field. Failures at proof in February, 1918, led to the decision that the use of cast iron sockets must be given up, as they failed to withstand the shock of firing, a return being made to the use of brass fuse sockets.[2] A number of shell with cast iron fuse sockets had, however, already been issued, and the prematures with 18-pdr. shrapnel shell that occurred in France in June, 1918, were thought to have been largely due to the collapse of the cast iron sockets.[3]

With a view to saving lead, the Metals and Materials Economy Committee investigated the desirability of substituting cast iron for lead bullets in shrapnel shell, but reported against such a change, unless and until lead or antimony became extremely scarce, since the efficiency of the shell would be seriously impaired, and the whole design would have to be altered. Lead became extremely scarce at the beginning of 1917,[4] and as the tonnage difficulties increased, the length of the Australian voyage kept supplies at a very low point. No suitable substitute for lead bullets could be found,[5] and the Ministry was therefore unable to supply the increased percentage of 18-pdr. shrapnel desired by the Army.[6]

Summarising the whole position as to the effect of the shortage of raw materials on the production of shell the supply department maintained that the unsatisfactory deliveries of the following stores were "entirely due to shortage of supply of materials, and not in any way to lack of manufacturing capacity, of which the most ample provision had been made":—4·5-in. H.E. shell; 18-pdr. H.E. shell; all natures of shrapnel shell, except 60-pdr.; No. 106 fuse; Hotchkiss base fuse; 18-pdr. cartridge clips; large base plates; copper bands; gaines, primers, exploder-containers, adapters, friction tubes and steel nose-bushes.

VI. Circulation of Metal Components.

When the Ministry began its work there was a great shortage of shell components, and shell works were frequently held up on account of the shortage of copper bands, base plates, gaines, shell noses and so on, or of the special shrapnel components—centre tubes, tin cups, discs, and bullets. In order to obviate this difficulty, the Gun Ammunition Department made arrangements to place further contracts for these components and to keep a stock of each component in bond, so that in case of difficulty, when their sub-contractors failed to deliver the quantity expected, contractors could come to the Ministry for help. Suitable small firms were selected for these contracts for components, and concentrated on the supply of a particular article. In this way, the Ministry avoided the uneconomical use of skilled

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[1] (Printed) *Weekly Report*, No. 77, II (27.1.17); A.M.3 A./1432.
[2] 14 February, 1918 (A.M.3 A./Shrapnel Supply/756).
[3] D.G.M.D./Mins.F/2.
[4] (Printed) *Weekly Report*, No. 77, II (27.1.17).
[5] Experiments with steel balls were made in November, 1917 (A.M.3 A/S/1809).
[6] *See* Vol. X, Part II, Chap. I.

labour which attended the manufacture of the same article by many firms in small quantities, and obtained components at very favourable prices.

Owing to the success of these arrangements, a movement began in the spring of 1916 for extending the Ministry's responsibility for the supply of components.[1] The Boards of Management first, later most of the National Projectile Factories, and finally the bulk of the direct contractors came into line, and by the date of the Armistice the only contractors who obtained components independently of the Ministry were certain of the armament firms.

The progress of the movement must be briefly summarised. In February, March and April, 1916, the Ministry placed large orders for shell components ; and the distribution of base plates and shrapnel components on a considerable scale began in April.[2] On 18 May, 1916, a price list of components was issued to all Boards of Management,[3] and on 22 June, the Boards were informed that all the components they required must be obtained from the Ministry, which undertook to supply them at a fixed price for the duration of the contract. A month later, the Leeds Board, which had bought a large number of shell noses, and other Boards were instructed that they were not to buy such components without finding out whether the Ministry could supply them. An application from the Liverpool Board of Management for permission to buy its own shrapnel components locally was refused on 15 September, and on 15 December the D.A.O. Committee was informed that an ample supply of shrapnel components for Board of Management contractors had been arranged for, and that components could be delivered so as to more than keep pace with the supply of forgings. There had been great difficulty however, about the poor quality of these components. Meanwhile, most of the English Projectile Factories were supplying their own components, but the Scotch ones were obtaining theirs through the Ministry. It was not found possible to supply the Scotch factories with all the components they required. In November, 1916, it was reported[4] that there were 17,000 8-in. shells at Cardonald waiting for base adapters, nose-bushes and copper bands, and the result was the suspension of some operations, disorganisation and dissatisfaction among the staff and the congestion of storage accommodation. Mr. West, therefore, decided that extra storage should be provided and the shell delivered into bond unbanded until the copper-band situation improved. In order to prevent some of the factories keeping an excess stock of shell components while others went short, it was decided (6 July, 1916) that components, like machinery, should be subject to the transfer system. Thus, when a shortage of nose-bushes threatened to restrict output in June, the 6-in. shell, which Leeds could not complete, were sent to Hackney Marshes, and Templeborough was supplied with 60-pdr. noses from Bridgeton and Newport.[5]

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[1] *See* above, p. 31.
[2] (Printed) *Weekly Report*, No. 37, III (8.4.16).
[3] D.A.O./C/7.
[4] N.P.F. Minutes, 2 November (250).
[5] N.P.F. Committee Minutes, 8 June, 21 July, 1916.

Unfortunately, however, there were many complaints from contractors in the summer of 1916 about the poor quality of some of the components supplied to them by the Ministry.[1] The defects appeared to be due to the shortage of gauges, and the consequent allocation of supplies of components without inspection. In order to remove this difficulty, the inspection of components was undertaken by the Gun Ammunition Department (15 September) until it could be taken over by the Inspection Department. In the meantime, the supply of components made to sample, but not inspected, was stopped, and it was arranged that the Contracts Department should not place any further contracts for these components until it had satisfied itself that the contractors were in a position to give deliveries satisfactory, both in quantity and quality. A number of the discs supplied to a contractor for 18-pdr. shrapnel were found to be defective, and the Ministry decided that the firms should be reimbursed the cost of rectifying these discs subject to proper safeguards (8 September).[2]

The general question whether it was or was not desirable for direct contractors to make their own arrangements for the purchase of components was discussed on 29 January, 1917. On the one hand, it was urged that contractors paid high prices for components with a bad effect on the Ministry's arrangements for purchase, on the other hand it was contended that these high prices often represented a better quality, and that complaints were frequently made of the inferior character of the components supplied by the Ministry and the cost of machining involved. Certain components supplied by the Ministry, for instance, base adapter forgings, were manufactured from crop ends, etc., and strict compliance with drawings and specifications were difficult. Further, the Ministry was not in a position to guarantee supplies of components.

The weight of the argument, therefore, favoured the policy of encouraging direct contractors to obtain their own supplies of components, and of limiting central purchase to building up a central store from which the Ministry could help contractors out of temporary difficulties. In negotiating shell contracts, however, contractors were to be informed as to the prices at which components could be obtained from the Ministry. Six months later the Ministry took a further step when it undertook to supply all contractors with certain components—copper bands, and base plates for 18-pdr., 4·5-in., 60-pdr., and 6-in. shell. The experimental character of this undertaking was insisted upon, as Sir Glynn West thought that there was a certain amount of danger in the Ministry undertaking the full responsibility for these components, as it would be liable for compensation if its arrangements broke down.[3]

At the end of 1916 it was decided that a National Component Factory should be set up at Tipton to make shrapnel components, and heads and nose-bushes for 6-in. shell. It was to be erected by the Ministry on land belonging to Messrs. Harper Sons & Bean, completion being

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[1] D.A.O. Committee Minutes, 20 July, 1916.
[2] *Ibid.*, 8 September.
[3] Shell and Components Committee Minutes, 23 July (424).

promised in three months.[1] The plant was to be obtained by the transfer of machinery for making components from the National Projectile Factories. Messrs. Bean were to supervise the erection of the factory and manage it on behalf of the Ministry without charge for their services. It was proposed that the firm should have the first option of purchasing the whole works and plant at their depreciated value, but the N.P.F. Committee anticipated some difficulty in this, in view of the Minister's decision that all National Projectile Factories must be on government freehold or on land held in a long lease. In the special circumstances the Minister was asked if he would permit an exception to be made in this case, and on 4 January it was reported that he had decided to do so.

Mr. West also suggested that a plant should be put down at Birmingham for the manufacture of brass stampings. Before sanctioning this proposal, Mr. Stevenson discussed the matter with the Birmingham Board and suggested that they should take over a shop already equipped by the Midland Manufacturing Company for this purpose, and standing idle. The Assistant Financial Secretary, however, decided that it would not be possible to take over the whole of these works.

In the meantime, the establishment of a shop for machining nose-bushes for the Newlay and Hunslet factories had been proposed, but it was considered undesirable in view of the scheme for the factory at Tipton.[2] A modified scheme was submitted (4 and 11 January), under which expenditure would be limited to the cost of re-arrangement of the plant for temporary use. On this understanding the proposal was approved on 11 January, 1917.[3]

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[1] N.P.F. Committee Minutes, 21 December, 1916.
[2] 21 December (N.P.F. Committee Minutes).
[3] D.D.G. (A.) 30564.

CHAPTER VI.

THE FINANCE OF SHELL PRODUCTION.

I. Control of Capital Expenditure.

(*a*) Capital Expenditure on the National Shell and Projectile Factories.

The way in which the original expenditure on the National Shell and Projectile Factories had been sanctioned has already been described.[1] The ever growing demand for shell led, however, to extensions of these factories which meant increased capital expenditure and a revision of the original estimates, all such proposals being sanctioned from the technical and financial point of view by the N.P.F. and D.A.O. Committees.

Sometimes a proposed extension was negatived owing to the time it would involve, sometimes it was condemned as extravagant, frequently it was accepted after expert examination with or without modification.[2] Many of the schemes for extension put forward by Boards of Management were subjected to searching criticism. The Ministry objected to schemes which appeared to be too permanent in character for this class of factory, and subjected the estimates, particularly the contingencies item, which was frequently large, to very severe criticism. Substantial savings were often effected in estimates without any sacrifice of efficiency, owing to the accumulation at headquarters of experience of various forms of lay-out, or methods of power transmission.

The Munitions Works Board was established in January, 1917, to exercise "a restraining supervision on new building schemes." There was a general feeling that some check ought to be put on new construction and factory extension, and the sanctioning of schemes involving new construction was transferred from the Assistant Financial Secretary to the Munitions Works Board.

The Shell and Components Committee, reluctant to have to refer all such proposals to the Board, thought that when a representative of the Assistant Financial Secretary was present at their meetings, and concurred in sanctioning a proposal, no reference to the Munitions Works Board should be necessary, and the Board agreed to this. On 30 April the committee went a little further and suggested that it should be empowered by the Munitions Works Board to give final sanction to items of expenditure below a limit of £1,000.[3] This proposal was agreed to on the understanding that a weekly list of all expenditure so sanctioned should be forwarded for the information of the Board.

[1] Assisted contracts stand in a class apart and are separately treated below.
[2] *See* N.P.F. and D.A.O. Committee Minutes, *passim*.
[3] Shell and Components Committee Minutes, February–April, 1917.

In order to keep some check on irregular expenditure, the Munitions Works Board decided that all cases in which the money had already been spent by the firm before sanction was asked for, were to be referred to it, even if the sum involved was less than £1,000.[1]

By the beginning of 1917, the National Projectile and Shell Factories were fully equipped, and the only considerable expenditure that had to be incurred was in connection with the adaption of machinery to new designs, the change over to lighter natures of shell, the introduction of labour saving devices, and of hydraulic shell testing appliances. But in addition to these various schemes, which were of considerable financial importance, there were a host of smaller schemes which involved comparatively small sums of money. In order not to be overwhelmed by a mass of detailed work of minor importance, the Shell and Components Committee gave the heads of the supply departments authority to confirm small orders for plant without reference to the committee, the interpretation of the term "small order" being left to the discretion of the heads of departments, no definite financial limit being imposed.[2] Even so a very large number of cases came before the committee for sanction. This routine work of supervision included the sanctioning of expenditure on minor additions to machinery, on new bond rooms and extensions of inspectors' offices, increased accommodation for component stores, extensions to power producing plant, and minor extensions to buildings, the provision of photostat apparatus and lacquering plant, extra cloak-room accommodation, stock rooms for storing overalls, ambulance rooms and a garage for storing ambulance cars, the provision of trolley ways, fire hydrants and so forth.[3]

During 1917, therefore, the control of the expenditure of the National Projectile and Shell Factories had become more and more a matter of routine. There were few attempts to evade the control of the committee and these were not of the first importance. On the other hand, the work of supervising the capital expenditure under assisted contracts, in which increasingly large sums of public money were invested, grew in volume and importance.

(b) CONTROL OF ASSISTED CONTRACTS.

The system of stimulating contractors to produce munitions of war by advancing them money for the erection of new plant had already been developed by the War Office before the formation of the Ministry.[4] Contracts of this type were known as assisted contracts, a term which is not susceptible of any exact definition, but which was used to cover any arrangement between a Government Department and a contractor which involved the provision of funds by the State for the erection of new plant.

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[1] Shell and Components Committee Minutes, *passim*.
[2] *Ibid.*, 5 February.
[3] D.A.O./9/213, 218; C.S.M. 30976; A.M. 6/Newlay P/1118; A.M. 6/Renfrew P/4; A.M. 3/Armley P/18; A.M. 3.c/Lancs. P/25.
[4] For types of these contracts, *see* HIST. REC./H/1300/9; 94/Gen. Nos./461.

As soon as the Ministry was established the need for closer financial control was at once apparent. Very large sums had been advanced to shell and fuse manufacturers under the various forms of assisted contract, but, owing to pressure and the need of haste, very little had been done to verify, check, or control the expenditure of the firms. It was naturally to their interest to equip themselves with plant as elaborate and beautiful as possible, and extravagant equipment became the rule rather than the exception. The money was advanced by the Government on the production of certificates of expenditure by the firms' auditors, but these certificates merely checked the fact that the money had actually been spent, and were no guarantee that it had been suitably or profitably spent. When the contract provided that the plant was to remain the property of the Government, the Department was in a stronger position, since the auditors were required to keep detailed lists of the actual buildings, plant and machinery covered by the government grant, showing the date at which each item was taken into use. There was still the difficulty that owing to the eagerness to obtain supplies, the estimates of contractors as to the extensions to plant that would be necessary were accepted with too little scrutiny. A memorandum by the Assistant Financial Secretary was considered at a meeting on 20 July, 1915,[1] and there was a general agreement that "no hard and fast code of rules could be adopted and that it would be necessary to follow different principles according to the standing of the firm concerned."

A considerable step forward was taken on 1 October, 1915, when it was arranged that a copy of all contracts involving capital advances for buildings or plant should be sent to the Assistant Financial Secretary, but as the contracts were only to be sent on completion, there was still no financial control in the wider sense, though there was some guarantee that the special terms of these contracts would be met by the adoption of suitable accountancy methods.[2] It was not until early in 1916 that the Finance Department obtained effective control of the preliminary negotiations, and was thus enabled to compare the value of the various schemes, and criticise the terms on which the advance of money was to be made.

The next step was to scrutinise the proposed extensions to plant from the technical point of view. The plans and estimates were submitted to the Area Engineers and to the engineers on the central staff of the Ministry, and by the spring of 1916, all proposals for capital expenditure were being scrutinised from the technical as well as the financial aspect. The plans of the proposed buildings had to be submitted for approval to the Ministry, together with detailed estimates of the total expenditure on land, buildings, plant, electrical plant and machine tools, and on jigs, chucks, etc. (exclusive of perishable tools), covered by the government grant. An estimate of miscellaneous expenditure on the erection of machines and factory equipment, making of roads, etc., and the sum set apart for contingencies was

[1] The meeting was attended by Mr. Booth, Mr. Geddes, Mr. Lever, Mr. Dannreuther, Mr. Harrison and Major Wedgwood (C.R./Filling/395).

[2] 94/Gen. Nos./244.

included. These estimates were not to be exceeded without the express consent in writing of the Ministry. The work of installing the plant was scrutinised on behalf of the Department by the engineer inspectors of the area, who furnished reports on the progress of the work. Any deviation from the approved plan and estimates was at once reported. Technical difficulties arising in the course of the installation were reported to the Ministry which gave any assistance in its power.

It was proposed that a priced inventory should be made of all plant in which the Ministry had an interest, and the plant was to be marked as the property of the Department under the supervision of section A.M.6. Unfortunately this instruction was not carried out. Inventories were begun but not completed, and it was not until 1918 that a proper system was set up by the Controller of Factory Audit and Costs and the Department of Engineering.[1]

The Ministry instructed the firms to take great care that "economy combined with efficiency was practised throughout the contract." Books showing all purchases which came under the government grant were to be strictly kept and were to be open for inspection at all times.[2]

When the N.P.F. Committee took over the control of assisted contracts, certain contracts for shell components were causing anxiety owing to the fact that the work of criticising the estimates and proposed lay-out had fallen into arrears.[3] In most cases, these were contracts under which advances made by the Ministry were repayable by deductions from the contract price. There were also a number of contracts where a simple loan had been made repayable with interest. It was decided that sufficient attention had not been given to these contracts in the past and that a much closer watch must be kept on them for the future,[4] all schemes for the production of similar stores being considered together, in order that the figures of different firms might be compared.

About the beginning of 1917, the Ministry extended the policy of investing public money in grants to assisted contractors for shell production, in lieu of building new government factories. It was recognised that the Department had already acquired far more plant than it was likely to be able to find use for after the war, and in the shell and fuse contracts placed from the summer of 1917 onwards, it was generally provided that the firm should be the ultimate owner of the buildings put up, the Ministry only advancing a percentage of the cost. In addition, the Ministry frequently advanced a portion of the working capital to bear interest at 1 per cent. over Bank rate, with a maximum of 5 per cent. It was usual to insert a clause binding the contractor to keep the plant and machinery at the disposal of the Ministry for three months after the termination of the war, and for a further three months at the option of the Ministry, and in many

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[1] *See* above, p. 77.

[2] 94/Glasgow/56.

[3] *Fuses :* Sterling Telephone Co., King's Norton Metal Co., Messrs. Singers, White & Poppé, Kent, Cubitt, Birmingham Metals and Munitions Co. ; *Cartridge cases :* Messrs. Christopher Collins, Kynoch (94/Gen. Nos./ 461. This file contains a general list of all assisted contracts for fuses, cartridge cases, etc.).

[4] 94/Gen. Nos./461.

contracts there was a paragraph stating that the plant to be provided under the agreement was as far as possible to be so designed as to be adaptable to ordinary commercial purposes.[1]

The assisted contracts for shell and components placed by the Ministry varied considerably in their terms, but they fell mainly into one or other of the following classes or into a combination of them[2] :—

(1) *Advance* by the Ministry on the following terms :—

(*a*) repayable over a period with interest, the ownership of the property remaining with the contractor ;

(*b*) with or without option to the contractor to purchase the property at a valuation after the war, the ownership in the meantime retained by the Ministry.

In either case the advance might be partly in cash and partly an issue of machinery, plant, etc.

(2) *Contribution* in cash by the Ministry, being a percentage of the approved expenditure on authorised works payable on their satisfactory completion, or from time to time during the progress of the work, according to agreement. This contribution might or might not be repayable by the contractor, according to the terms of the contract.

(3) *Guarantee* by the Ministry of the difference between a certain percentage on the approved expenditure and the amount allowed to be written off the cost by the Inland Revenue authorities for the purpose of computing excess profits duty, in the event of the latter sum being less than the former.

(4) *Re-imbursement* in certain cases by the Ministry of approved expenditure incurred by the contractor.

In spite of all these efforts and instructions there were a number of cases in which there was no reliable record of the advances made to contractors. Technical certificates were not available for a large part of the expenditure prior to the formation of the Munitions Works Board. In some cases machinery was supplied to contractors without invoices, and no proper record was available in the books of the Accounts Department of the Ministry. There was even, in some cases, considerable uncertainty as to the amount of capital expenditure authorised, the records of approval being mislaid. Auditing could not be complete and satisfactory until these obscurities were cleared up, and from 1 May, 1918, a new system was introduced by the Controller of Factory Audit and Costs.[3]

There were a number of cases in which the assisted firms exceeded the estimates of capital expenditure which had been passed by the Ministry. Strict enquiry was made, and the items of the excess were investigated on the spot, and usually allowed, if the total cost of the scheme did not exceed that of similar schemes, the value of the comparative method being strikingly demonstrated in work of this kind,

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[1] *e.g.*, assisted contracts with Messrs. J. F. Low & Co., 20 February, 1917 (94/Glasgow/56).

[2] *See* Memorandum on the Audit of Capital Expenditure, July, 1918 (Copy filed in Hist. Rec./R/430/2). For a list of these assisted contracts, *see* Hist. Rec./H/1300/9.

[3] Hist. Rec./R/430/2.

especially in connection with estimates by firms who had no previous experience of shell making.[1]

Certain difficulties arose over and over again in administering these contracts. The estimates of capital expenditure allocated definite sums to definite items, but the contractors frequently overspent on some items, arguing that this practice made no difference to the Ministry, provided they kept within the limits laid down for the whole expenditure. The insistence of the Ministry on the detailed items being adhered to, or sanction for variation being asked for, was not a mere accountant's quibble, as it appeared to many of the firms, but was based on the fact that the original detailed estimates had been scrutinised and adjusted from the technical as well as the financial point of view, and that a departure from these estimates might upset the balance of the plant.[2]

II. Factory Costs and Cost Investigations.

(a) THE BEGINNING OF COST ACCOUNTING.

The key to the whole system of Ministerial control of the shell factories lay in the expert use of statistics. Any factory where output was poor or costs high could be detected at once, and the number of factories from which statistics were drawn was large enough to enable those in which conditions were similar to be grouped together for the purpose of comparing their performances.

The first steps towards introducing this system on its financial side were taken on the advice of Mr. Lever in the autumn of 1915, when the Cost Accounting Branch was established to receive monthly cost returns from every government factory. These returns were prepared according to a scheme set out in detail by the Ministry, methods of book-keeping and cost-keeping being organised on a uniform basis.[3]

A system of cost accounting had been in operation for many years at the Royal Arsenal, Woolwich, the labour and material cost being distinguished and proper allowance being made for overhead charges, but the value of the system was diminished by the fact that the costs were not got out until about nine months after the end of the year. Thus Woolwich costing was academic rather than practical, and it was useless for control purposes. There was no special novelty, therefore, about the system of factory accounting introduced by Mr. Lever, but its application to a very large number of factories all producing similar munitions was entirely new, and the results were more valuable as a basis for reaching a standard cost. Costing systems had been introduced into all the National Shell Factories by 20 November, and in the week ending 11 December the first cost returns were

[1] N.P.F. Committee Minutes, 23 November, 1916; C.S.M. 30579; Shell and Components Committee Minutes, May, July, 1917.

[2] *See*, for instance, 94/Glasgow/56.

[3] HIST. REC./R/450/1. Circulars were sent to National Shell and Projectile Factories on 4 and 5 November, 1915, and to National Filling Factories on 6 November.

received. The returns from Keighley, where 18-pdr. shell had been made at a cost of 9s. 7d. per shell, were a revelation, and the Finance Committee set up by Mr. Lloyd George in January, 1916, took up the position that ascertained costs of production must be the basis of all prices, and that 10 per cent. upon the manufacturing costs was a fair profit for a firm engaged in munition making.[1]

(*b*) The Value of Cost Returns.

The story of the Ministry's campaign for the reduction of shell prices, which, owing to the overwhelming needs of the Army, the hard bargains made by the armament firms (who had a monopoly of experience and suitable machinery), and the inexperience of Boards of Management, had reached a fantastic level, is told in detail elsewhere.[2] Here it is sufficient to draw attention to the fact that the chief lever by which the Ministry obtained the substantial reductions in price was the experience it had gained of the actual costs of production in national factories. The costings system was also of immense value in fixing prices for contracts for new designs of shells, fuses and so on, and in placing contracts which were to be worked on a co-operative or profit-sharing basis. During 1916 and 1917, a number of large and important contracts were placed upon this co-operative basis—*viz.*, at cost, plus a bonus for production and a bonus for economy—and thus the number of factories in whose costs of production the Ministry was directly interested was largely increased.

As time went on, and cost returns were received from an increasing number of factories—the Shell and Projectile Factories, the Explosive Factories and the Filling Factories—it became possible to work out average costs for the production of a large variety of munitions of war. These costs were based upon the average output from plant of an average nature.[3] They included depreciation of plant at 33⅓ per cent. per annum, depreciation of buildings at 10 per cent. per annum, interest at 6 per cent. on working capital, and were based on steel at fixed prices.[4] The figure was therefore higher than that of a first class firm with modern equipment, but lower than that of an ill-equipped factory. Theoretical or technical costings were also worked out for new components or new types of munitions, based upon the estimated cost of material and the estimated machining cost.

A later report on the costing system[5] may be quoted here to explain the principles upon which it was based.

> "The costing system is in the circumstances very properly based upon wages, and not upon machine power. From the point of view of war time finance it may be objected that the accounts are even too minute in the appropriation of oncost

[1] The committee, consisting of Mr. Lever, Mr. Rothschild, Mr. John Mann and Mr. Frederick Palmer, and held its first meeting on 10 January; Minutes of Finance Committee (M.W. 75517; C.R. 4441).

[2] Vol. III, Part II.

[3] C.R. 4441. M.W. 75517.

[4] £15–£18 10*s*. 0*d*. per ton according to the size.

[5] Report to the Minister by the Financial Advisory Committee, 20 June, 1917.

charges, while from the point of view of peace time work it may be objected that a more scientific system than one based entirely upon wages should be adopted.

"The Committee is satisfied, however, that at the early stages of production of the factories it was essential that all costs should be most carefully collated and ascertained. The value of any system of costing depends very largely for practical purposes on the rapidity with which costs can be ascertained. Costs which, however accurate, are forthcoming months after the production has occurred are, as a rule, of comparatively little assistance to the manager in charge of production."

Cost returns, however, were a weapon that always needed careful handling, and they might be mischievous rather than useful unless used by people who had a knowledge of the circumstances. Extremely high costs might be quite justifiable owing perhaps to a shortage of steel, to a change over from one Mark to another, or to the fact that production was just beginning or just ceasing. High costs again might be due to a high percentage of rejections caused by defective steel not by bad machining. The general rule followed in considering costs of production was to regard the rate of output as the governing factor. Large factories were expected to produce shell at a lower cost than small factories, and it therefore became possible and useful to compare figures which on the face of it showed striking discrepancies.

Again, the costs of production returned for National Projectile and Shell Factories were to some extent artificial, as raw material and components were supplied by the Ministry at fixed prices. In the absence of a free market for steel, for instance, it is not clear how the fixed price of £15 a ton compared with the real price, but the method of arranging a fixed price had the advantage of simplifying comparisons by eliminating minor fluctuations, differences in freight, and so on.[1] All these factors had to be considered and allowed for, and judgment on cost returns was therefore expert work not lightly to be undertaken by the uninitiated.

The Ministry met this difficulty by appointing a staff of supervisory engineers, whose duty it was to visit all the factories where costs were unsatisfactory, in order to see whether they were due to causes beyond the factory's control, or to difficulties that might be remedied—bad machining methods, unsatisfactory management, poor equipment, or the like. High costs were taken as the danger signal, and in any case where the cost worked out at less than 25 per cent. below the current contract price, an investigation was ordered.[2] Thereupon, detailed information as to the cost of materials, wages, and oncost, together with an example of good manufacturing practice on the same mark of shell was given to the Efficiency Branch (A.M.3) of the Shell

[1] The Metropolitan Munitions Committee had bought steel at £12 a ton, but the D.A.O. Committee asked that it should be charged out to contractors at £15 a ton, as all shell prices had been based on the latter figure. (D.A.O. Committee Minutes, 28 July, 10).

[2] Select Committee on National Expenditure, Ministry of Munitions, Sub-Committee, 22nd Meeting.

Manufacture Department, which usually undertook an investigation on the spot. For this purpose a supervisory engineer from headquarters, accompanied by the superintendent engineer of the area, visited the factory. The former, being an engineering expert, and having behind him the accumulated shell-making experience of the Ministry, was armed with full technical knowledge of the best methods of manufacture and of the time to be taken over each operation, while the Area Engineer, who was usually familiar with the factory, was able to give information as to the special conditions of local manufacture. They investigated the management and supervision of the factory, the tool-room, the manufacturing methods and sequence of operations, the supply of power, the use of labour-saving devices, the progress and inspection systems, and so on. In reporting on the factory, due allowance was made for all local conditions—the supply of power, the class of machinery in use, the character of the labour employed, and the percentage of women workers—and for failures in the supply of steel and components. The chief causes of the high costs or poor output were pointed out, and as a rule definite recommendations were made as to the balancing of plant, new methods of manufacture, further dilution or the like, which made all the difference between success and failure.[1]

The ascertainment of these average costs had the direct effect of improving manufacturing methods. Contractors were compelled to look closely into their costs of production, to overhaul their methods and reduce waste. The fact that the Ministry not only had the power of scrutinising a firm's books (which, it may be said, was but rarely used), but also the knowledge what average costs should be, gave it a very strong hand in negotiations, and kept the standard of shell manufacture up to a high level of efficiency. The effect of the application of this system to the Ministry's own factories can hardly be overrated. The cost returns of factories became the test of their efficiency and high costs were the signal for investigation and remedial measures.

(c) Development of Cost Investigations in 1917.

The use of cost investigations as a means of raising the general standard of shell manufacture is a striking feature of 1917. Economy, as well as output, had become the catch-word. An elaborate system of progress reports[2] had reduced the spasmodic "hustling" of early days to an exact science, and the Shell and Components Committee, which controlled the whole field of shell manufacture was increasingly occupied with the comparison of cost returns as an index of efficiency.

As in 1916, cost returns were obtained at intervals from national factories and from assisted contractors, but these tables had become more detailed as time went on, an attempt being made to analyse costs of production more closely than before.[3] The co-operation

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[1] Examples of these cost returns are given in Hist. Rec./H/1300/9.

[2] *See* above, Chap. I.

[3] In factories where the oncost was high, special investigations were undertaken to analyse the incidence of oncost charges, *e.g.*, Hackney Marshes National Projectile Factory, November, 1916 to March, 1917.

between the finance and the supply departments with regard to these returns had become closer as their importance became more apparent. The Finance Department supplied the manufacturing department with the complete statistical cost tables, and pointed out any matter to which, in their opinion, the attention of the management of the factory should be drawn. Any special points were discussed at the weekly meeting of the Shell and Components Committee, and, on 16 April, 1917, it was decided that Mr. T. H. Judd, of the Accounts Department, should be responsible for drawing the attention of the Shell Manufacture Department to all cases of high cost returns which required investigation at the factory by an inspector of the Efficiency Branch.

As its name implied this branch set out to find, and if possible remove any difficulty which hindered the production of good shell at a low price. It was, therefore, concerned with engineering, as well as financial questions, with the use of labour, of power, and shell handling appliances, and with manufacturing methods generally. To guide them in this, a mass of information had been accumulated on the equipment and output of the factories, the nature of which may be illustrated by the reports on the National Projectile Factories, which were at once the most important and the most exhaustive.

(*d*) REPORTS ON NATIONAL PROJECTILE FACTORIES.

During their periodical visits to the National Projectile Factories, the inspectors of the Efficiency Branch compiled tables giving details of the number, make, etc., of the machines in use, the methods of machining in force, the actual times taken for the various operations, and the number of shells that it would be possible to pass through each operation in a week of 120 hours.[1] These tables, which showed clearly the balance or want of balance of machines in the factory, were the standard by which its output was judged. At the same time, the principle of working out "ideal times" for each of the operations on a typical machine was adopted. These ideal times were worked out in the Efficiency Branch, and were communicated to manufacturers and engineers forming a kind of "bogey score," up to which the factory was to work. These ideal times were considered in relation to the nature of the factory's equipment with machines and shell-handling appliances, and a "standard time" (the factory's ideal score under handicap rules) was thus obtained for each operation at each factory.

The returns required and obtained from the National Projectile Factories were, in view of their size and importance, both intricate and exhaustive. Each factory filled up every month an "efficiency chart," giving figures of the skilled, semi-skilled and unskilled labour, and of the women and boys employed. The labour employed was classified as direct or indirect labour, direct labour being grouped as machine operators and other hands, and the return of indirect labour distinguishing those employed inside and outside the factory. There was a further sub-division into groups of operations. The numbers

[1] Select Committee on National Expenditure, Ministry of Munitions, Sub-Committee, 22nd Meeting.

of tool-room staff, electrical staff, building, maintenance and management staff were separately recorded. The chart also contained statements of the number of shells in the factory at the beginning and at the end of the period, the number of hours during which the machinery had run, the output of good shell and parts of good shell, and the number of rejections of shell or parts of shell. It also included a statement of the amount of time lost, labelled as "excusable" or "reprehensible."

Another report—"the machine progress report"—was called for weekly. This showed the number of machines available for each operation on the shell body, the number of machine hours worked, and the output for each operation. The rejections on each operation were tabulated, distinguishing between forging and machining faults. This return, therefore, showed the average time taken for each operation and it was compared with the "ideal time" for the operation as calculated by the Ministry, having regard to the nature of the machines and the equipment of the factory. An "efficiency figure" was given to the factory based on the proportion between the actual and ideal times taken over the various operations which formed a useful index of the comparative value of the factories.

This by no means completed the number of returns asked for by the Efficiency Branch. In addition, there was the "rejection summary," which summarised the rejections at the factory and in bond, distinguished between shell which could be rectified and scrap, and showed the proportion of scrap and rejected shell to total output. A ready test of shop management was provided by obtaining separate returns of shell spoilt during machining. A weekly "forging report" showed the output of forgings, the percentage of good forgings, the number of hours worked compared with the number of hours which might have been worked, the average output per press hour worked, the average output per worker per press hour worked, and the average output per worker per hour.

All this laborious and minute work found its vindication in a comparative table showing the work of all the National Projectile Factories, classified according to the nature of the shell made by them. This table recorded the machine hours actually worked with the machine hours that could possibly have been worked. It showed the average hours per shell body (obtained by dividing the total number of hours actually worked by the number of shell delivered into bond) and the average production of shell bodies per employee. The figure of machining efficiency as calculated above was also recorded, and the whole formed an example of the practical application of the principles of scientific management on a scale hitherto unknown in England. Careful statistical work of this kind had a value in educating engineering opinion quite apart from its immediate object, but it could, of course, only be adopted in full in industries in which there was a large amount of repetition work. This very elaborate system was not extended to the National Shell Factories, which were on a much smaller scale and showed much more variety in equipment, and the chief index of their efficiency was found in the cost returns prepared by the Finance Branch.

A rough table of the comparative costs of 18-pdr. shell in 1917 is given in Appendix IV. as an indication of the nature of these cost returns.

(e) REPORT OF THE FINANCIAL ADVISORY COMMITTEE ON COST RETURNS.

The system above described was submitted to a searching inquiry by the Financial Advisory Committee in June, 1917, and it came well out of the test.[1] The committee, with Mr. Judd's help, examined the accounts of the National Projectile Factories, and selected one set of returns—those of the Nottingham Factory for the five weeks ending 27 January, 1917—for detailed examination. The committee was satisfied that the system, so far as it related to the actual costs, provided all that was necessary for proper record and supervision. The methods adopted enabled the costs to be traced through the various stages of manufacture, showed the separate cost of each operation, and afforded a ready means for comparison with costs of other national factories, and for showing up any excessive expenditure. The committee also considered that the system of investigating these costs in section A.M.3 was satisfactory, and enabled them to be used to obtain economy and efficiency in production.

The report continued :—

> "The weak factor in the whole series is the delay which takes place before the various costs and accounts are forwarded from some of the factories (notably Lancaster, Renfrew, and Hackney Marshes). . . . Certain of the factories seem to be unduly lax in this respect, and the excuse of insufficient staff and difficulties of organisation, even though admissible at an earlier stage of production, cannot now be accepted, unless the Finance Department is prepared to acquiesce in being permanently late in receiving the returns from those particular factories. As the remaining factories seem to be able to send up their returns in reasonable time, every effort should be made to bring the tardy factories into line."[2]

The committee suggested that the ascertainment of costs might be hastened if the oncosts of one month or quarter were adopted temporarily as a working factor for the following period. This might apply to all cases in which production was of a repetition character and of standard quality, where the variation in the rate of oncosts would be slight. Depreciation of plant and buildings, interest on capital, and remuneration of managing firms, had no direct effect upon working costs, and it might be sufficient, therefore, to arrive at the real cost of the product to the State by half-yearly or yearly allowances. The comparison as between factories, to be in any degree accurate, must be based on equal equipment, and therefore, the real capital cost per shell could only be proved by actual output, not by estimated shell producing capacity.

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[1] HIST. REC./R/450/6.

[2] In reply to a remonstrance about their delay in sending in cost returns Messrs. Babcock & Wilcox excused themselves by the difficulty of finding skilled accountants (D.F.C. 403).

Any disturbance of routine resulted in increased oncosts, and this fact had to be kept in mind when attempting to compare costs. When a factory was changed over from one product to another the oncosts might be so disturbed as to affect the total price to a material extent. Shortage of material, temporary breakdown of plant, holidays, strikes and the like, might upset all comparative costs. Thus, though the costs at one National Projectile Factory might form a good argumentative ground for comparison with another factory, local conditions and special drawbacks would have to be taken into account in arriving at a decision whether proper economy had been exercised in production.[1]

Occasionally the enquiries and suggestions of the Efficiency Branch made singularly little impression and repeated visits led to no improvement. Criticisms of inefficiency were met by countercharges of failure on the part of the Ministry to supply material and components, and it was difficult to pin down the management to a definite responsibility for remedying defects. In such cases, the best remedy appeared to be a joint visit to the factory by four or five officers of the Ministry representing the departments dealing with labour, the supply of materials, stores and finance, as well as engineering and other representatives of the Shell Manufacture Department. The visit lasted for two or three days, at all events for long enough for the officers to get a full knowledge of the working of the factory from the management downwards, each expert looking at it from his own angle and emphasising the chief cause of failure from his own point of view. These independent reports being collated, a clear picture of the factory emerged with its weak points indicated by expert opinion. The views of the management were asked for to clear up points on which there was a possibility of misunderstanding. On such reports the Ministry recommended definite action to be taken by the management of the factory, and in theory, though not always in practice, the factory was then left severely alone to work out its own salvation and to remedy defects without nursing or interference from the Ministry. If there was no improvement, after the expiration of a reasonable period of grace, the Ministry had a strong case for proposing the only possible remedy—a radical alteration of management. This, for instance, was the course followed at Hackney Marshes, and when the failure of repeated visits, interviews and remonstrances dating from 31 May, 1916, onwards[2] became apparent, the management of the factory was ultimately taken over by the Ministry on 1 August, 1917.

Fortunately, there were few cases, in 1917, of National Shell Factories requiring drastic treatment of this kind. In 1916, when the shell factories were learning their business, there had to be constant interference by the Ministry,[3] but by 1917 the majority of them had adopted modern methods of management, and there were few cases where reorganisation was needed. Edge Lane National Shell Factory

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[1] The actual working of this system in 1917 is illustrated by some concrete examples in Hist. Rec./H/1300/9.

[2] Hist. Rec./R/1122.4/4; N.P.F. Shell Committee Minutes, 2 April (172), 23 July (432), 30 July (456), 20 August (485).

[3] *See* above, pp. 72–75, for illustrations of this.

was one of the factories at which there were still serious difficulties which could not be cured by the visits and suggestions of the Efficiency Branch, and a new manager was appointed by the Ministry.

(*f*) COSTS OF NATIONAL PROJECTILE AND SHELL FACTORIES.

By far the most important of the investigations which were undertaken in 1917 was the enquiry whether the National Projectile Factories, whose success from the point of view of the output of heavy shell was generally admitted, had been equally successful from the financial point of view. An investigation of the accounts of the factories up to 31 March, 1917, when they had been working nearly a year, gave results which were generally regarded as satisfactory. The average cost of shell produced in the National Projectile Factories compared very favourably with the average contract price, as may be seen from the following table :—

Nature.	Average cost of shell in National Projectile Factories (including depreciation) for period ending 31 March, 1917.	Average contract price during period.	Contract prices, April, 1917.
	s. *d.*	*s.* *d.*	*s.* *d.*
60-pdr. H.E. ..	43 8	51 3	43 6
60-pdr. S. ..	54 5	57 6	54 0
6-in. H.E. ..	63 2	69 3	62 6
8-in. H.E. ..	100 7	156 3	125 0
9·2-in. H.E. ..	170 10	217 6	192 6
12-in. H.E. ..	441 2	442 0	410 0
15-in. H.E. ..	772 0	985 0	800 0

It was calculated that the capital expenditure upon this group of factories amounted to £6,832,040. The total output of the group to March, 1917—3,798,403 accepted shell—had cost £13,619,211 to produce, or £14,659,327 including depreciation (£775,030) and the management commission £265,086. This cost compared with the contract rates prevailing throughout the year showed a saving of about 2¾ million pounds or 18 per cent.[1] An allowance for depreciation at the rate of 30 per cent. for plant and 10 per cent. for buildings had already been made, and the saving of 2¾ million pounds would be sufficient to write off half the remaining capital expenditure. In other words, the saving from the first year's production seemed sufficient to meet the difference between the original cost and the probable realisable value of the factories.

In preparing this statement as to the results of the working of the National Projectile Factories the Finance Department pointed out that, though some of the factories began manufacturing about March,

[1] For the detailed figures, *see* the tables given in HIST. REC./H/1300/9.

1916, production on a large scale was not reached until about November, 1916, and that the first year's costs therefore included the starting up period, which was at the same time a period when rapid output was the primary, and economical production a secondary consideration. Secondly, though the more successful factories had reached an output of fully 50 per cent. above their estimated capacity, they had all suffered from a shortage of steel, which since January, 1917, had seriously reduced their output and unfavourably affected their costs of production. Again, changes in design and methods of manufacture, which, of course, retarded output and increased costs, had generally been tried at the National Projectile Factories rather than thrown upon contractors, and the adaptability of the National Projectile Factories under these conditions had been a great asset to the Ministry. It was therefore fair to state that the results of the first year's working, satisfactory as they were, did not fully represent the standard of efficiency and economy which the factories had reached. Another point to be considered when estimating the value of the factories from the financial point of view was that their working had also saved public money indirectly, since their cost returns had provided most valuable data for reducing contract prices for the larger ratures of shell manufactured by contractors, just as the National Shell Factories' costs had done with the smaller natures of shell. They might also be credited with saving money in another direction, since if they had not been turning out large quantities of heavy shell, the Ministry would have been forced to place additional orders for this class of shell in America at higher prices than those charged by British contractors.

A similar enquiry into the working of the National Shell Factories up to 30 September, 1916, also showed good results.[1] There was a marked improvement in their performances in the last half of 1916, as appears from the following table, which compares the average factory cost per shell (including depreciation) with the average contract prices prevailing during the same manufacturing period :—

Nature.	Manufacturing period ending 31 March, 1916.		Manufacturing period ending 30 Sept., 1916.		Contract Price, April, 1917
	Average Factory Cost.	Average Contract Price.	Average Factory Cost.	Average Contract Price.	
	s. d.	s. d.	s. d.	s. d.	s. d.
13-pdr. H.E. ..	16 10	17 9	—	13 0	9 6
18-pdr. H.E. ..	19 4	20 0	14 6	15 0	12 6
4·5-in. H.E. ..	42 5	60 0	26 5	33 6	28 10
60-pdr. H.E. ..	—	70 0	49 4	52 6	43 6
6-in. H.E.	126 5	90 0	72 11	75 0	62 6
8-in. H.E.	—	210 0	128 0	160 0	125 0

[1] 24 April, 1917.

All the National Shell Factories were installed in premises leased or lent to the Ministry, and there was, therefore, no capital expenditure on land and comparatively little on buildings. Up to 30 September, 1916, only £159,870 had been spent on buildings. The expenditure on plant to the same date amounted to £980,116, the total capital expenditure therefore on thirty factories amounted to £1,139,986.[1] The total cost of the shell produced in the factories from the time when they began production up to 30 September, 1916, was about £3,750,000. A comparison of this cost with the prevailing contract prices showed a saving of about £314,736, after writing off depreciation at 30 per cent. on the plant and 10 per cent. on the buildings, which amounted to £270,000. Thus the saving effected by the factories (£314,736), together with the depreciation written off in the costs (£270,000), was equal to nearly one half of the capital expenditure.

This result, satisfactory enough on the face of it, becomes more striking when it is remembered that in most cases the National Shell Factories were at a great disadvantage compared with National Projectile Factories or the armament firms. The factories were small and scattered, they were adapted to shell production from the most diverse uses,[2] and their equipment was often antiquated, unsuitable and extravagant. Moreover, the National Shell Factories, as a whole, had singularly bad fortune in that the demand for light shell fluctuated violently during 1916. In the spring of 1916 they reached their full output, but a change in War Office requirements made it necessary to reduce the output of 18-pdr. shell very drastically in the summer of 1916, with a result that many of the National Shell Factories had to be changed over to other work. The output of 18-pdr. shell was kept at a very low level for some months in the autumn of 1916, while the output of 4·5-in. shell was also greatly reduced for lack of forgings. It was not until early in 1917, that the National Shell Factories were allowed to produce shell at their full capacity. Manufacture was therefore constantly interrupted, and the costs of production were much higher than they would have been had the factories been allowed a free run. The fact that these costs of production compared so favourably with contract prices during the period is a tribute to the supervision generously given without fee or reward by the Boards of Management throughout the country.

Another enquiry which gave very striking results was that into the value from the financial point of view of assisted contracts of the co-operative type (31 March, 1917). The seven firms grouped together as the Glasgow Shell Scheme had produced 601,517 shell at a cost of £1,223,310 which showed a profit of £275,000 over the same production on a flat-rate basis.[3] This saving had been made on a capital expenditure of £526,984.

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[1] *See* HIST. REC./H/1300/9, Appendix II, for figures of the expenditure on the factories individually.

[2] Grimsby was formerly a fish-curing factory; Cardiff a rope factory; Newport a locomotive shed; Nottingham, a lace-making works; Bacup, an old weaving mill; Bradford, a vacant woollen mill.

[3] For details, *see* table in HIST. REC./H/1300/9 (Appendix III).

III. Revision of Contract Prices.

(a) Schedule of Prices.

As has been seen, the cost returns obtained from national factories in the autumn of 1915 proved that the prices paid to contractors in the past had been far too high.[1] The principle of laying down a general scale of prices for direct contractors was therefore adopted, and a scale of prices for all natures of shell from 2·75-in. upwards was circulated at a conference with the armament firms on 3 February, 1916.[2]

H.E. Shell.	*Output.*	*Price.* £	s.	d.
2·75-in.	1,000 per week	0	11	0
,,	2,000 ,, ,,	0	10	6
,,	2,000 and over per week	0	10	0
13-pdr.	1,000 per week	0	11	9
,,	2,000 ,, ,,	0	11	3
,,	2,000 and over per week	0	10	9
18-pdr.	3,000 per week	0	13	0
,,	4,000 ,, ,,	0	12	9
,,	5,000 and over per week	0	12	6
4·5-in. Mark V.		1	13	6
,, Mark VI.		1	14	0
60-pdr. Mark V.		2	9	6
,, Mark VI.		2	10	0
6-in. Mark XV.		3	7	6*
,, Mark XVI.		3	8	0*
8-in. Mark III.		7	15	0
9·2-in.		10	10	0
12-in.		20	5	0
Shrapnel Shell.				
13-pdr.		0	16	0 (17s. to 30 April to new contractor).
18-pdr.		0	18	9
60-pdr.		2	15	0

* Plus 6d. for change-over.

This list was revised later on at intervals. The principle was gradually extended to cover shell components and other munitions

[1] 94/S/1853, 2048, 2569, 2634. For a more detailed account of the campaign for the reduction of shell prices, *see* Vol. III, Part II.
[2] 94/S/2048.

or parts of munitions for which the Ministry was placing contracts. After protracted negotiations, the armament firms accepted a reduction of prices,[1] and from this time onward orders for shell were only placed at or below the standard price, except in very special circumstances. In August, 1916, Mr. Lever estimated that the reduction of prices had saved 20 millions sterling on the home supplies of shell, while American and Canadian shell prices had been reduced by 15 and 12½ per cent. respectively, as compared with the 1915 prices.[2]

The following table compares shell prices in the United Kingdom, in the United States of America, and in Canada, in April, 1916 :—

	United Kingdom.		U.S.A.		Canada.	
	Average of contracts.	Standard price, July, 1916.				
	£ s. d.	£ s. d.	£ s. d.	$	£ s. d.	$
15-in. ..	55 0 0	—	63 3 0	300	—	—
12-in. ..	21 2 0	21 2 0	32 15 0	155	—	—
9·2-in. ..	12 0 0	11 7 6	13 5 0	63	13 5 0	63
8-in. ..	8 10 0	7 17 6	8 8 6	40	8 16 10	42
6-in. ..	4 0 0	3 10 0	3 13 5	17·50	3 7 4	16
60-pdr. H.E...	2 12 6	2 12 6	3 3 2	15	2 6 3	11
60-pdr. S. ..	2 17 6	2 17 6	2 16 10	13·50	—	—
4·5-in. ..	2 0 0	1 14 0	3 1 0	14·50	—	—
18-pdr. H.E...	0 15 0	0 12 6	1 1 0	5	1 0 2	4·80
18-pdr. S. ..	0 19 0	0 18 6	1 6 6	6·30	1 1 0	6·0
13-pdr. H.E...	0 12 0	0 9 6	—	—	—	—
13-pdr. S. ..	0 16 0	0 16 0	—	—	—	—

Note.—$4·75 are taken as equivalent to £1.

At the same time contracts for fuses, gaines and T tubes showed a reduction of 40 to 50 per cent. on pre-Ministry prices.[3]

All contracts placed or renewed after 30 September, 1916, contained a break clause giving the Ministry power to terminate at 14 days' notice, subject to the proviso that the Ministry took over materials and components in the possession of the contractor at cost price, and indemnified the latter against commitments reasonably incurred for the purchase of materials and components.[4]

By the spring of 1917 prices had again been reduced, as appears from the following table giving the contract prices for the principal natures, and comparing them with costs at national factories.

[1] Vol. III, Part II.
[2] HIST. REC./R/400/5.
[3] 94/S/2075 ; 94/F/164.
[4] 94/S/4198 ; 94/Gen. Nos./460.

REDUCTION IN SHELL PRICES & COMPARISON WITH AVERAGE COST IN NATIONAL FACTORIES.

Size of Shell.	Contract Prices.			National Factories' Costs, including Depreciation (18-pdr. and 4·5-in. in National Shell Factories, and other natures in National Projectile Factories.)	
	1914–15.	March 1916.	March 1917.	Average Cost 1916–17.	Lowest Monthly Cost 1916–17.
	s. d. s. d.	s. d.	s. d.	s. d.	s. d.
18-pdr. H.E. ..	20 0 to 23 0	12 6	12 6	14 6	8 11
4·5-in. H.E. ..	47 0 to 65 0	33 6	27 10	26 5	24 3
60-pdr. H.E. ..	63 0 to 82 4	52 6	42 0	43 8	36 7
6-in. H.E. ..	80 0 to 99 0	70 0	61 6	63 2	49 0
8-in. H.E. ..	183 4 to 200 0	157 6	132 6	107 0	92 2
9·2-in. H.E. ..	262 6 to 305 0	227 6	187 6	170 0	149 3

Note.—Prices at March, 1917, provide for recent rise in wages of 5*s.* per week.

Meanwhile, steps had been taken to fix the prices to be allowed under Board of Management contracts, which in the early days of area organisation had shown the most amazing variations, even making all allowances for local conditions. From September, 1915, onwards, schedules of maximum prices, which were not to be exceeded by the Boards of Management in placing contracts, were issued at intervals. These schedules were subsequently revised, at first in the direction of lower prices, but after the beginning of 1917, slightly higher prices were allowed, to compensate for higher wages. Experience showed that these maximum prices were generally regarded as standard prices, and with the exception of a few contracts in the London Munitions Area, no contracts were placed at less than the maximum allowed.

Occasionally, during the currency of a contract, a change of circumstances made the price fixed when the contract was placed unremunerative—or at all events less remunerative—to the contractor, and in such cases an appeal was made to the Ministry for an increase of price. Such claims were made for a variety of causes, of which the following were the chief: increased wages, changes in design, and faulty material or components.

(*b*) Increased Prices due to Increased Wages.

On 10 April, 1916, the Treasury had laid down the principles on which claims by contractors for increased prices due to increased wages were to be treated.[1] It took the view that contractors had

[1] 94/Gen. Nos./353.

no ground for expecting to be re-imbursed the extra wages they had paid in accordance with the awards of the Committee on Production. The conditions of the labour market resulting from the war were such that an increase of wages sooner or later was inevitable, and it was probable that many contractors in submitting tenders took into consideration the fact that an increase would probably occur. The burden of proof, therefore, lay upon the contractor, who had to demonstrate that the increase of wages justified him in asking for an increased payment, and in the case of a company or firm having several contracts with the Government, an application would not be considered without reference to the total result of all such contracts, supported by an examination of the firm's books. A clause in Board of Management contracts provided for the manufacturer claiming an amount equal to the proved extra cost per shell, which would have to be substantiated in each case. This policy held the field until the beginning of 1917, when a general rise in wages led to renewed pressure on the part of contractors for a revision of prices, and in January, 1917, in accordance with a pledge previously given by Mr. Montagu at a meeting of Boards of Management, a form of clause was settled for Board of Management contracts for shell and components, which provided for an increase in the price of shell, should the wages of those employed in connection with the contract be raised by the action of the Ministry.[1]

In May, it was announced that the extra price paid for 18-pdr. H.E. would be 1¼d. per shell on account of the January rise in wages, and 5d. per shell on account of the January and April rise combined.[2] The Ministry stated that this increase of prices was to be subject to the distinct understanding that it would be a final settlement of all claims against the Department by contractors working under Boards of Management on account of the rise in wages, "except in the event of a grant of a further increase in wages affecting existing contracts."

The Ministry tried to limit the number of contractors who applied for an increase of price by laying down rather stringent rules defining the limits within which such applications would be accepted[3] (5 July, 1917). The stipulation that the Ministry would consider the financial result of the firms' contracts for government work as a whole, was in itself sufficient to rule out applications from the armament firms and the big shell contractors generally. Further, the contractor who applied for an increase had to show that the contract was being executed to the satisfaction of the Department, and that the increase of wages had deprived him of the "reasonable profit he should in the opinion of the Ministry have secured." Moreover, every claim was to be subject to an independent investigation by the Ministry's accountants, of the figures and accounts on which it was based. The contractor had to make a statutory declaration of the total cost of carrying out the contract in materials, non-productive and productive labour, establishment charges and of the amount of the total profit obtained under the contract. It was further laid down by the Ministry that when the

[1] (Printed) *Weekly Report*, No. 75, II (13.1,17); D.A.O./C/15.
[2] Shell and Components Committee Minutes, 14 May (271); D.A.O./C/16.
[3] P.M./Gen. No./734; Contract Department Branch Memo. No. 100.

delivery of any part of the contract was in arrears, increased wages incurred during the period of delay were not to be included in the claim.

(c) CHANGES IN PRICE DUE TO ALTERATIONS IN DESIGN.

The policy adopted by the Ministry with regard to changes in price due to alterations in design was defined in April 1916.[1] Estimates of the additions to or deductions from the price which might be considered reasonable were drawn up by the Production Department and communicated to the firms or Boards of Management concerned. If they refused to accept this, one of the Ministry's inspecting engineers visited the factory concerned and investigated the question. In the case of changes involving a reduction of price, the Ministry stated the reduction proposed and waited for protests from the firms which were to be dealt with by the inspecting engineers.

This system worked smoothly[2]; generally speaking modifications in design were met by modifications in price without much difficulty, the existence of machinery for producing technical costings being a great help to the Contracts Department.

(d) COMPENSATION FOR FAULTY MATERIAL OR COMPONENTS.

In order to meet cases where faulty material or components had been supplied by the Ministry, or where there had been a serious shortage of materials, a revision of prices was allowed. The question of paying contractors for work done on defective steel or forgings supplied by the Ministry, was a difficult one. It first became prominent in June, 1916, and after discussion a decision was arrived at which allowed compensation to Board of Management contractors, but left direct contractors uncompensated.[3] The question was again discussed on 11 June, 1917. The existing practice of Boards of Management under which the Department of Area Organisation was empowered to meet all such claims was thought to be too generous. There was a fairly general agreement that, while genuine cases of hardship should be considered by the Shell and Components Committee, there should be an effort to bring the Board of Management practice into line with the practice in force for direct contractors.

(e) PRICES TO BE PAID FOR LIGHT SHELL.

A certain amount of light shell which would otherwise have been rejected was accepted for proof of fuse and powder filling, the price paid being 10 per cent. below the contract figure for good shell. This figure appeared to be too high, and in November, 1916, the D.A.O. and N.P.F. Committees recommended that the price should be one third of the contract price for good shell, and on 22 December this price was approved.[4]

In order to economise steel a scheme for accepting (at a deduction from the normal contract price) all light weight or slightly defective shell which was found suitable for service was brought forward by the

[1] 94/Gen. Nos./423.
[2] *e.g.*, 94/S/2499.
[3] D.A.O. Committee Minutes, 16 July, 16 June, 28 July, 1917.
[4] *Ibid.*, 13 December, 22 December, 1916; D.G.I.M./S/293.

Inspection Department and the Raw Materials Branch[1]. The natures of defective H.E. shell accepted for proof of fuse were the following :—13-pdr., 15-pdr., and 18-pdr., 4·5-in. howitzer, 4·7-in. howitzer and 60-pdr. The only defect permitted was that of being too light or too heavy ; the shell was to be correct in other respects.

The need of economy, however, led to this standard being relaxed. It was decided in March, 1917, that shell with other faults was to be accepted, and a comprehensive scheme, drawn up by Commander Lloyd, which classified shells according to the nature of their defects, the scale of payment being varied to correspond was accepted, special financial provisions involving a reduction in their bonus being inserted to penalise carelessness on the part of assisted contractors and the firms managing the National Projectiles Factories.[2]

IV. Costs of Management.

Under the original agreement, the armament firms under whose supervision the factories were constructed, had to pay the salaries of the chief manager only. The staff appointed by the chief managers were paid by the Ministry, and arrangements were made to watch this class of expenditure.

Comparatively few points in connection with the commission payable to the managing firms came before the N.P.F. Committee. The usual practice was to submit a statement of expenditure properly audited, the commission being then paid.[3] In view of the reduction of work and increase of output at National Projectile Factories making 60-pdr. shrapnel, which would result from the setting up of a National Component Factory at Tipton, it was agreed, on 21 December, 1916, that a corresponding reduction should be made in the commission payable to the managing firms.[4] A minor point, settled on 14 December, 1916, was that no commission should be allowed to the managing firms on shell rejected for H.E., but accepted for powder filling.

It was decided that the commission on the capital expenditure payable to the managing firms should not be continued after 31 December, 1916, since the services in respect of which this payment was made had come to an end with the completion of the equipment of the factories to produce their rated output. The work now devolved upon staff in the pay of the Ministry, and some of the managing firms had themselves suggested that no further payment should be made.

The managing firms continued to receive their bonus on each shell produced. On 20 August, 1917, however, it was reported that Messrs. Vickers had agreed to waive further commission on output at the Lancaster factory, and that negotiations were proceeding with Messrs. Hadfield to secure the same result.[5]

The Financial Advisory Committee regarded the system by which the remuneration of the managers depended upon output, irrespective

[1] D.A.O. Committee minutes, 13 December, 1916.

[2] Shell and Components Committee Minutes, 5 March, 12 March.

[3] *e.g.*, Commission to Messrs. Harper, Bean & Son on £250,000 (N.P.F. Committee Minutes, 23 June (75)).

[4] C.S.M. 29756. [5] Shell and Components Committee Minutes, 20 August.

of the cost at which that output was produced, as unsound in principle. Some portion, at least, of the remuneration should, depend upon output being forthcoming at a reasonable cost.[1]

V. Arrangements for recovering Value of Materials supplied by the Ministry.

The supply of steel, steel forgings, copper bands, and other shell components to contractors by the Ministry created a financial, or rather an accountancy problem, which was not dealt with very successfully. As has been seen elsewhere,[2] the methods of accounting which the Ministry inherited from the War Office were not suitable to record the transactions of the great trading concern into which the Ministry grew, and there was for a long time no adequate machinery for keeping track of and accounting for materials and components supplied by the Ministry. Thus there was a possibility of serious leakage which was strongly criticised by the Public Accounts Committee.

The Ministry began its work on the assumption that the material supplied would be paid for promptly, but when it was found that credit would usually have to be allowed, it was arranged that 1⅝ per cent. should be added to the price where four months' credit was required.[3]

On 25 September, 1916, Mr. Hanson suggested that the principle, already adopted in Manchester, of supplying steel forgings and copper bands to firms at current rates, recovering *per contra* from the money due to them for shells should be extended.[4] This proposal had many advantages over the existing system, under which the Ministry theoretically received payment as soon as the material was supplied. Many of the contractors who had recently taken up shell contracts were very short of money owing to the need of financing their new extensions, and the attempt to obtain immediate payment for shell material or components was becoming unworkable. On 26 November, 1915, therefore, it was decided that the system of recovering *per contra* (*i.e.*, by means of deduction from bills which become due) the value of materials or components supplied by the Ministry would be adopted as a general rule. Care was to be taken to see that the financial standing of the firm was unquestionable.[5] Special provisions had to be inserted in certain contracts—notably Swiss contracts for fuses—to secure that the material provided by the Ministry did not fall into the hands of the enemy.

As has been seen[6] shell steel was supplied by the Ministry at fixed prices. Lists of prices at which shell components and raw materials for shell components were supplied to contractors were issued, but in order to simplify accounting these prices were not revised to follow fluctuations in the actual cost of producing the component. As long as the discrepancy between the issued price and the actual cost was not considerable, no difficulty arose. If the price, however, was too low, there was a danger that contractors might dispose of components and there was also a loss on shells supplied to the Allies.[7]

[1] Hist. Rec./R/450/6. [2] Vol. III, Part II. [3] 94/Gen. Nos./234.
[4] *Ibid.* [5] 94/Gen. Nos./234. [6] *See* above, pp. 82–84. [7] P.M./Gen. Nos./778.

CHAPTER VII.

REVIEW.

The Ministry of Munitions was created to supply more shells for the Army, and throughout its existence the production of gun ammunition was by far the largest branch of the Department's activity, accounting as it did for more than half of its total expenditure. [1]

During the war period, over £900,000,000 was spent upon the gun ammunition actually issued to the troops, while enormous stores of unfilled shell and shell components were left over. The organisation of shell manufacture which has been outlined in the preceding pages formed, of course, only part of the work of gun ammunition production; the remainder of the task—the supply of explosives and propellants and the fusing, filling and completing of the shell—form the subject of the two following parts of this volume.

In some respects, the production of empty shell, though the largest, was one of the simplest of the Ministry's tasks. The decision that national factories must be set up to fill the gap between demand and supply was the vital factor; once this decision had been taken, the problem became merely one of accelerating output and making the best use of capacity already created. Long before the end of the war, the National Shell and Projectile Factories had proved themselves capable of surpassing the maximum production assigned to them, but the dearth of steel prevented them from being run to their full capacity, and this resulted in the transfer of some shell factories to other work, especially to the manufacture and repair of guns, which were proving insufficient for the volume of ammunition available for them. Shell production, therefore, reached its climax in 1917; in the following year steel shortage compelled a diminished production, and the chief energies of the Department were devoted to pressing on the supply of new types of shell to provide for chemical warfare, defence against aircraft, and long range bombardment on a greatly extended scale.

Owing to this creation of manufacturing capacity it became possible to reduce the dependence upon overseas supplies of empty shell, which in 1915, represented nearly one-half of the total. This proportion was steadily reduced falling to one-fourth of the total in 1918, by which date Canada was producing a much larger, and the United States a much smaller amount than before, which from the political and financial point of view was a great advantage. In addition, the setting up of the national factories re-introduced competition, and enabled the Department not only to produce shell cheaply for itself but to reduce the prices paid to contractors.

The creation of the huge output of the new factories should not be allowed to obscure the contribution of the direct contractors. Aided largely by loans and grants from the State, these contractors

[1] *See* Appendix V.

raised their output more than forty-fold. In 1914 and 1915, they produced two-thirds and three-fourths respectively of the home output of empty shell, and in 1918 were still producing more than one-third of that output. Production by Co-operative Groups was also on a large scale; they turned out nearly as many shells as the Ordnance Factories and the National Shell and Projectile Factories put together, though the bulk of their output was in light and medium natures. The part played by Woolwich was remarkable. In addition to acting as the experimental factory for many new types—in conjunction with the National Projectile Factories which also did work of this kind—Woolwich increased its production more than twenty-fold—from 77,300 shells in 1914 to 1,821,300 in 1918.

Shell manufacture on this enormous scale had important reactions on the engineering industry. It gave opportunities for the mass production of standardised products, developed the use of automatic machinery and labour-saving devices, utilised women's labour, and familiarised the industry with the manufacture of accurately dimensioned stores, and with the use of precision gauges. It benefited the industry also on the financial side by the close comparison of production costs in money, labour, and material, by the scrutiny of overhead costs, and by developing the habit of co-operation among firms in the same trade.

APPENDICES

APPENDIX I.

(CHAPTER I, p. 8.)

Summary of First Shell Programmes (July—September, 1915.)

Nature.	Weekly Requirements.			Maximum July Programme.	Maximum September Programme.	Total Orders placed.		Percentage of Requirement.		Additional Orders to be placed under September Programme.
	August, 1915.	December, 1915.	June, 1916.			July.	September	July.	September.	
								per cent.	per cent.	
18-pdr. S. ..	153,300	196,600	268,400	268,400	383,500	509,700	575,300	190	150	65,600
H.E. ..	153,300	196,600	268,400	268,400	383,500	504,200	575,300	188	150	71,100
15-pdr. S. ..	9,980	9,980	—	—	—	—	—	—	—	—
H.E. ..	29,940	29,940	—	—	—	—	—	—	—	—
*13-pdr. S. ..	10,500	11,900	14,000	18,550	36,050	27,820	54,100	—	—	—
H.E. ..	10,500	11,900	14,000	18,550	36,050	27,820	54,100	—	—	—
4·5-in. How. S. ..	11,530	16,890	31,360	31,360	5,000	47,040	7,500	150	133	—
H.E.	46,100	67,580	125,440	125,440	219,000	203,400	328,500	162	133	85,860
†5-in. How. H.E...	8,400	8,400	8,400	8,400	—	8,400	—	100	100	—
60-pdr. S. ..	3,570	10,080	29,870	39,200	56,000	53,520	74,670	134	133	22,140
H.E. ..	3,570	10,080	29,870	39,200	56,000	53,200	74,670	134	133	21,470
4·7-in. Gun S. ..	4,620	4,620	4,620	—	—	—	—	—	—	—
H.E.	4,620	4,620	4,620	—	—	—	—	—	—	—
6-in. Gun S. ..	840	1,010	1,010	1,010	—	—	—	—	—	—
H.E. ..	840	1,010	1,010	1,010	—	—	—	—	—	—
6-in. How. H.E. ..	8,960	14,000	46,670	78,400	126,000	105,060	168,000	134	133	62,940
8-in. How. H.E. ..	2,520	3,360	7,560	7,560	45,150	10,130	60,200	134	133	50,070
‡9·2-in. How. H.E.	2,180	3,530	9,330	25,200	30,070	33,370	40,100	134	133	6,330
12-in. How. H.E...	160	1,560	2,690	2,690	4,260	3,600	5,680	134	133	2,080

* After December, 1915, the ammunition requisitioned for this gun would probably need to be increased.

† 500 Shrapnel per week had also been ordered at home.

‡ Maximum to be reached in December, 1916, except in 9·2-in. when maximum would not be reached until February, 1917.

APPENDIX II.

(CHAPTER III, p. 45.)

Manufacturing Programmes for United Kingdom, 1917 and 1918.

Nature.	1917 PROGRAMMES.			1918 PROGRAMMES.			
	Oct., 1916.	7 March, 1917.	13 April, 1917.	24 May, 1917.	10 July, 1917.	3 May, 1918.	23 Sept., 1918.
18-pdr. H.E. ..	600,000	435,000	No alteration	1,080,000	450,000	368,000 (including Chemical).	180,000
Shrapnel ..	300,000	300,000	No alteration		300,000	400,000	410,000
4–5-in.	154,000	175,000 rising to 190,000	140,000	192,000	228,000	240,000 (including Chemical).	200,000
60-pdr. H.E. ..	48,500	30,000	No alteration	132,000	63,000	85,000 (including Chemical).	52,500
Shrapnel ..	63,500	35,000	No alteration		63,000	61,000	18,500
6-in. Howitzer ..	141,000 rising to 145,000	144,000	No alteration	180,000	163,000	220,000 (including Chemical).	150,000
6-in. Gun H.E. ..	8,000	5,400	No alteration	20,000	7,500	9,900	24,000
Shrapnel ..	5,750	5,400	No alteration		9,000	5,200	11,000
8-in. Howitzer ..	50,000	36,000	20,000	35,000	45,000	21,800	26,000
9·2-in. Howitzer ..	33,000 rising to 43,000	24,000	5,000	30,000	27,000	10,900	16,000
12-in. Howitzer ..	5,000	—	—	1,000 (subject to review).	—	840	800

APPENDIX III.

(CHAPTER III, p. 67.)

Output of Empty Shell, 1914–18.

(*Figures in thousands*).

	1914.	1915.	1916.	1917.	1918.	Total
Light.						
Ordnance Factories ..	63·4	1,017·9	1,426·2	1,158·2	724·5	4,390·2
National Shell Factories ..	—	147·0	2,934·7	4,291·3	4,640·1	12,013·1
National Projectile Factories	—	—	—	919·1	708·8	1,627·9
Co-operative Groups ..	—	472·6	6,219·3	10,969·5	11,176·8	28,838·2
Direct Contractors	136·5	5,006·5	10,419·7	14,049·0	18,979·6	48,591·3
Total Home	199·9	6,644·0	20,999·9	31,387·1	36,229·8	95,460·7
Abroad	—	7,145·0	30,079·7	15,056·0	6,256·0	58,536·7
Total Light Shell ..	199·9	13,789·0	51,079·6	46,443·1	42,485·8	153,997·4
Medium.						
Ordnance Factories	13·9	190·4	386·3	368·6	185·0	1,144·2
National Shell Factories ..	—	15·1	1,009·6	2,577·8	2,523·0	6,125·5
National Projectile Factories	—	37·3	1,124·5	2,558·7	3,317·3	7,037·8
Co-operative Groups ..	—	46·2	2,848·6	4,398·8	4,154·6	11,448·2
Direct Contractors	31·4	1,187·1	3,121·6	3,961·2	4,421·1	12,722·4
Total Home	45·3	1,476·1	8,490·6	13,865·1	14,601·0	38,478·1
Abroad	—	713·6	8,664·4	5,336·0	3,221·7	17,935·7
Total Medium Shell ..	45·3	2,189·7	17,155·0	19,201·1	17,822·7	56,413·8
Heavy.						
Ordnance Factories	—	1·0	2·0	·1	5·8	8·9
National Shell Factories ..	—	1·0	195·9	715·9	812·5	1,725·3
National Projectile Factories	—	—	864·8	2,921·7	4,138·3	7,924·8
Co-operative Groups ..	—	1·5	641·5	1,609·8	1,347·3	3,600·1
Direct Contractors	—	80·5	996·0	2,798·9	4,205·8	8,081·2
Total Home	—	84·0	2,700·2	8,046·4	10,509·7	21,340·3
Abroad	—	142·1	1,662·1	4,135·4	8,498·5	14,438·1
Total Heavy Shell ..	—	226·1	4,362·3	12,181·8	19,008·2	35,778·4
Very Heavy.						
Ordnance Factories	—	—	6·8	9·2	8·9	24·9
National Shell Factories ..	—	—	14·7	109·7	38·6	163·0
National Projectile Factories	—	—	568·5	1,700·7	1,257·1	3,526·3
Co-operative Groups ..	—	—	129·9	255·3	78·3	463·5
Direct Contractors	·2	110·4	777·9	1,265·3	1,097·5	3,251·3
Total Home	·2	110·4	1,497·8	3,340·2	2,480·4	7,429·0
Abroad	—	21·7	1,442·3	3,005·6	353·8	4,823·4
Total Very Heavy Shell	·2	132·1	2,940·1	6,345·8	2,834·2	12,252·4
Totals.						
Ordnance Factories	77·3	1,209·2	1,821·3	1,536·1	924·2	5,568·2
National Shell Factories ..	—	163·1	4,154·9	7,694·7	8,014·2	20,026·9
National Projectile Factories	—	37·3	2,557·8	8,100·2	9,421·5	20,116·8
Co-operative Groups ..	—	520·3	9,839·3	17,233·4	16,757·0	44,350·0
Direct Contractors	168·1	6,384·5	15,315·2	22,074·4	28,704·0	72,646·2
Total Home	245·4	8,314·5	33,688·5	56,638·8	63,820·9	162,708·1
Abroad	—	8,022·4	41,848·5	27,533·0	18,330·0	95,733·9
Grand Total	245·4	16,336·9	75,537·0	84,171·8	82,150·9	258,442·0

APPENDIX IV.

(CHAPTER VI., p. 103).

Costs of 18-pdr. H.E. Shell in 1917.

Nature.	Factory.	Mark.	Month.	Wages.	Oncost.	Material.	De-preciation.	Total Cost. (including credit for scrap)	Contract Price.	Production. 4 Weeks' Basis.
				s. d.	s. d.	s. d.	d.	s. d.	s. d.	
18-pdr. H.E.	Workington	III.	Jan. ..	1 4	1 5	5 3	8	8 8	12 6	9,343
			July ..	1 7	2 3	5 4	9	9 9	12 11	10,308
	Dublin	III.	Jan. ..	1 9	2 11	5 11	10	11 5	12 6	13,372
			July ..	1 4	2 2	5 8	10	9 9	12 11	24,102
	Dundee	III.	Feb. ..	1 4	1 5	6 0	9	9 6	12 6	10,595
			April ..	1 4	1 1	5 9	9	8 7	12 6	27,111
	Nottingham	III.	Feb. ..	1 8	3 2	5 8	9	11 3	12 6	8,976
			July ..	1 7*c*	2 8	5 7	9	10 2	12 11	11,975
	Carlisle	III.	Feb. ..	2 0	3 4	5 8	9	11 9	12 6	5,437
			March ..	1 5	3 0*a*	5 8	9	10 3	12 6	6,617
	Bristol	III.	Feb. ..	6 8*a*	4	5 8	3	12 11	12 6	38,518
			June ..	6 7	5	5 6	3	12 5	12 11	75,804
	Liverpool (Lambeth Road)	III.	Jan. ..	6 9*a*	1 1*a*	5 6	3	13 7	12 6	21,889
			May ..	6 5	1 0	5 5	3	12 8	12 11	31,245
	Keighley	III.	Feb. ..	2 1	6 11	5 11	9	15 8	12 6	887
			March ..	1 8	3 3	5 11	9	11 7	12 6	2,019
			April ..	1 11	3 2	5 5	9	11 3	12 6	3,123
	Huddersfield ..	III.	March ..	2 0	5 4	5 9	9	13 11	12 6	3,466
			May ..	1 8	2 8	5 9	9	10 4	12 11	13,452
	Cardiff	III.	March ..	1 9	8 11	5 5	9	16 9	12 6	3,198
			May ..	1 3	4 6	5 7	9	11 9	12 11	14,790
	Wrexham	III.	March ..	1 7	6 6	5 4	3	13 0	12 6	1,320
			April	1 9	4 2	5 4	9	11 7	12 11	2,242
	Swansea	III.	May ..	2 0	2 4	5 4	9	10 1	12 11	3,522
	Dudley N.P.F. ..	III.	June ..	4 10*b*	10 2	5 2	9	20 9	12 11	2,206

(*a*) Completing sub-contractors' shell; sub-contractors' charge of 6s. 2d. per shell included in direct wages.
(*b*) Initial stages of production. (*c*) Breakdown reduced output and increased cost by about 3d. per shell.

APPENDIX V.

(CHAPTER VII., p. 115).

Expenditure on Gun Ammunition during the War Period.[1]

(*Based on number of shell filled, i.e., excluding stocks in August,* 1914 *and including stocks in the Field in November,* 1918).

	£	s.	d.
13-pdr. 6-cwt.	5,345,075	0	0
13-pdr. 9-cwt.	9,832,225	0	0
15-pdr.	1,398,000	0	0
18-pdr.	317,161,600	0	0
10-pdr.	233,700	0	0
2·75-in.	808,800	0	0
2·95-in.	217,080	0	0
3·7-in.	346,000	0	0
6-pdr.	2,280,700	0	0
12-pdr.	181,020	0	0
3·20-in.	4,371,800	0	0
4-in.	60,800	0	0
60-pdr.	75,585,650	0	0
4·7-in.	4,131,525	0	0
4·5-in.	129,088,987	10	0
5-in.	1,985,150	0	0
6-in. Gun	15,672,000	0	0
6-in. Howitzer	187,148,300	0	0
8-in. Howitzer	71,019,000	0	0
9·2-in. Gun	2,882,000	0	0
9·2-in. Howitzer	72,700,000	0	0
12-in. Gun	634,000	0	0
12-in. Howitzer	9,920,000	0	0
15-in. H.E.	2,100,000	0	0
Total	£915,003,412	10	0

[1] Sec./Gen./2635.

Volume X

THE SUPPLY OF MUNITIONS

PART IV

GUN AMMUNITION: EXPLOSIVES

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CHAPTER I.

DEVELOPMENTS IN THE USE AND MANUFACTURE OF EXPLOSIVES.

I. Characteristics of British Service Explosives.

The explosives needed for military and naval purposes fall into three great classes, viz.: (1) propulsive explosives, the main purpose of which is the ejection of a projectile from a gun or a bullet from a rifle; (2) high explosives, used chiefly as a bursting charge for various projectiles, for naval mines, torpedoes and also for engineering purposes; and (3) initiating agents, which cause explosion in substances belonging to either of the other classes.

At the outbreak of hostilities in August, 1914, the propulsive explosive generally used in the British Navy and Army was cordite M.D.; the only approved bursting-charge for high explosive shell was picric acid (lyddite); gun-cotton was the charge used for naval mines and torpedoes; gunpowder or "black powder" was the burster for shrapnel shell and was also used for fuse compositions. Tetryl (C.E., or "Composition Exploding"), picric powder and finely powdered T.N.T. were all approved for purposes of detonation, *e.g.*, in fuse detonators or exploder bags.

Throughout the war, continued efforts to improve the safety and efficiency of ammunition and to effect supply in unprecedented quantities led to radical changes in the nature of the service explosives. Substitutes were adopted from other countries; new explosives were invented; new mixtures were accepted; new methods of manufacture and use were evolved. These developments were sufficiently remarkable in the case of propulsive explosives, which had long been standardised and of which the conditions of production were well-known. They were still more so in the case of high explosives. Military experience of these had been comparatively limited and industrial knowledge had been confined mainly to the manufacture of picric acid, used originally as a dye-stuff. The enormous advances made in their use and supply stand high among the most notable achievements of the war. It is proposed to describe in this introductory chapter the main features of these developments, which gave shape to the whole outline of explosives supply.

II. Propulsive Explosives.

The essential characteristic of propulsive explosives is that combustion takes place comparatively slowly from the only surface, so that the development of pressure, instead of being instantaneous, is gradually increased and imparts a continuous acceleration to the projectile during its passage up the bore. Cordite M.D., the standard British propellant in August, 1914, is composed of nitroglycerine, guncotton, and mineral jelly in the proportions 30, 65 and 5. It had superseded in 1901 the original cordite Mark I, which contained a higher proportion of nitroglycerine and had a calorimetric value of 1,150 units as against the 950 units of cordite M.D., thus causing much greater erosion in the gun.

(a) Method of Making Cordite.

In producing cordite, the nitrocellulose is first manufactured by treating cotton waste with strong nitric and sulphuric acid and the nitroglycerine by a similar treatment of refined glycerine. The nitroglycerine is poured on the nitrocellulose and roughly mixed by hand into a "paste." The final gelatinisation of the fibrous nitrocellulose and its intimate admixture with the nitro-glycerine is then effected by incorporation in a kneading machine by the agency of a solvent, *e.g.*, acetone or ether-alcohol, the mineral jelly being added during the operation. The product, known technically as "dough," is transferred to cylinders and forced by hydraulic or screw pressure through a die, the nominal size of the cordite being denoted by the number of hundredths of an inch in the diameter of the die. The cords are cut into the required lengths for gun ammunition and placed on wooden trays in drying stoves heated by hot water or steam ; for rifle cordite they are wound on reels before drying. The bulk of the solvent is thus driven off, recovered and collected for further use. The drying operation takes from two days to eight weeks, according to the size of the cordite, and the buildings required for this purpose occupy a very considerable area.

(b) Use of Nitrocellulose Powder.

Cordite is a double-base explosive manufactured from nitroglycerine and a nitrocellulose, and was preferred for British use on account of its reputation for general efficiency and also because its known stability made it safe to store it on ship-board, or to use it in the hotter climates of the British Empire. A single-base propellant was made and used by many other countries. In particular, large quantities of nitrocellulose powder were made in the United States of America by gelatinising nitrocellulose with a volatile solvent, ether-alcohol.

The chief obstacle to utilising any American propellants was the need for standardising these untried powders with the high-grade cordite used by the British services. The difficulty was complicated by the fact that American nitrocellulose powders had not been subjected to the stringent stability tests laid down by the British services. A very high standard of stability was particularly important in the larger sizes where any ignition was likely to have far-reaching effects.[1] Standardisation of American cordite and of the nitrocellulose powder was effected by means of a "master" standard of cordite sent out to the American proof-ranges, where the corresponding ballistics for a suitable lot of nitrocellulose powder were determined by firing trials under the British inspecting officer. The lots of nitrocellulose powder thus tested were then used as standards in proving other consignments.[2] It was laid down in March, 1915, that nitrocellulose powder up to a certain fixed size should be used for emergency purposes by the Expeditionary Force in Europe and that nitrocellulose small arm ammunition

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[1] Contracts/N/524. [2] Contracts/N/534.

should be issued without restriction.[1] Its acceptance for these purposes thenceforward enabled the army to draw more than 50 per cent. of its supplies of propulsive explosives from overseas,[2] and towards the close of the war the tendency was to supersede rifle cordite by nitrocellulose powder throughout the service, retaining cordite only for use in ordnance.

(c) INTRODUCTION OF CORDITE R.D.B.

The use of alternatives to cordite M.D. was pressed upon the War Office by the Admiralty in January, 1915, as a means of releasing greater quantities of the more stable explosive for naval service.[3] The limiting factor in expanding production of the service cordite was the amount of acetone which could be imported, since the home manufacture of acetone had not then been fully exploited, and supplies were entirely dependent upon the American market, which was of a very delicate nature.[4] During February and March, 1915, consideration was given to the practicability of converting British cordite capacity for the manufacture of nitrocellulose powder, since this explosive was made from ether-alcohol, a solvent which could be produced at home. The project was eventually abandoned in May, 1915, in favour of a new form of double-base propellant known as cordite "R.D.B."[5] The new cordite was evolved by the Research Department, Woolwich, to give the same ballistics and to have the same calorimetric value (950 units) as cordite M.D., by modifying the character of the nitrocellulose so that it should be soluble in ether-alcohol. This involved the use of the ingredients in a different proportion. The new cordite was considered superior to nitrocellulose powder in regard to chemical stability and efficiency and had great ballistic stability. It had certain important practical advantages in addition to its manufacture from a home-produced solvent. It could be produced on the same plant as service cordite. It dried more rapidly and used less gun-cotton than cordite M.D. or nitrocellulose powder.[6] After samples had been manufactured in the small experimental plant at the Research Department, Woolwich, the method of production was tested on full-sized plant at the works of a neighbouring firm during the months of May and June, 1915.[7] Cordite R.D.B. was sanctioned conditionally for the land service on 15 July, 1915[8]; but cordite M.D. was still preferred for naval purposes. Experimental manufacture of R.D.B. cordite was put in hand by the established cordite makers, who were called into conference as to the practicability of changing over to the new form of explosive on 10 June, 1915.[9] Their ultimate success in introducing the new form of cordite is described below.[10]

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[1] *Ordnance Board Annual Report* (1915), p. 649.
[2] See below, pp. 101-102. [3] C.P./101881/14. [4] See Vol. VII, Part IV.
[5] *Ordnance Board Annual Report* (1915), pp. 649-650.
[6] *Ordnance Board Minutes*, 13127. [7] S.R./14373/43
[8] *Ordnance Board Annual Report* (1915), p. 638.
[9] 74/6/3658. [10] See below, p. 100.

III. High Explosives.

The chief disadvantage of picric acid, the high explosive bursting charge in use at the outbreak of war, was its property of forming dangerous salts. Suitable precautions were taken to enable its safe use in shells, but these entailed special treatment of the empty shell, as well as numerous precautions in the manufacture and handling of the explosive.

(a) Methods of Making Picric Acid.

The basic raw material for picric acid was phenol, or carbolic acid, one of the aromatic compounds derived from coal-tar, which are also the basis of aniline dyes. The normal British method of making picric acid in peace time was based on traditional usages which had been in vogue in the dye industry for more than a century. The carbolic acid crystals were mixed by hand with sulphuric acid in earthenware baths, and left to stand for 24 hours. The resultant sulphonic acid was ladled out as a buttery mess into earthenware pots, into which nitric acid was then introduced very gradually. When nitration was complete, soluble impurities were removed by washing the picric acid in water, at first by hand, later by means of mechanical stirrers. It was then dried in lightly-built wooden stoves, where it was spread on glass plates heated by steam pipes. Owing to the risk of explosion, the stoves were generally situated at some distance from the rest of the building.[1]

Stoneware pots were used, since the acids were somewhat dilute and no metal was proof enough against their corrosive action to serve as nitrators. In consequence, it was difficult either to regulate temperature or to provide for stirring during nitration.

The enormous expansion in the production of picric acid was only attained by extending the basis of the raw materials used and by adopting novel and more efficient methods. In addition to manufacture from coal-tar or natural phenol, picric acid was made during the war from synthetic phenol derived from benzene through benzene sulphonic acid and from di-nitro-chlor-benzene, a dye material also derived from benzene.

(b) The Introduction of T.N.T.

At the outbreak of war picric acid was about to be superseded by T.N.T., an explosive which was more convenient to handle and comparatively safe. It was known chemically as tri-nitro-toluene, and was based upon another coal-tar product, viz., toluene. Since 1901, when its use had been suggested by certain dye makers who were producing it as a bye-product for export, investigations had been carried on as to its general properties and with a view to providing a satisfactory means of detonation, since it was less sensitive than picric acid.[2]

The priming charge originally employed with picric acid was an exploder filled with picric powder, a mixture of ammonium picrate and potassium nitrate, used in conjunction with a black powder fuse.

[1] Hist. Rec./R/1500/14, Chap. V. [2] *Ordnance Board Report*, No. 9.

This system was unsatisfactory with picric acid and not powerful enough to bring T.N.T. to detonation,[1] while a fulminate mixture was then considered too dangerous for service use. In October, 1909, a direct action fuse (No. 18) was adopted for coast defence service. It ensured complete detonation of either explosive by means of tetryl used in conjunction with exploder bags of finely powdered T.N.T.[2] By this time the Research Department had worked out the methods of making and purifying tetryl[3] and had investigated the general properties of T.N.T., reporting in July, 1908, that it was a safe explosive to introduce into the service and that it possessed certain advantages over picric acid.[4] A standard T.N.T. specification was drawn up at the same time; but picric acid was retained as a bursting charge for all H.E. shell on the ground that the difficulty of detonation would be aggravated by changing over to T.N.T.[5]

This decision was made in December, 1908, *i.e.*, before the introduction of fuse No. 18. Experiments with T.N.T. continued during the next few years. It was taken into service use by many European countries and others employed it in admixture with ammonium nitrate, or nitrate of lead. Its adoption was seriously considered by British authorities in view of experience gained during the Balkan war (1912-13). At the same time the advantages of T.N.T., and particularly its comparative safety, were impressed upon naval and military officials by outside experts. In January, 1912, the Explosives Loading Company was formed for the express purpose of gaining experience in the filling of projectiles with blocks of T.N.T.; but no orders were placed with it by the British Government.

The Research Department amplified its previous report on T.N.T. in February, 1913[6], and experiments were carried out at the Royal Laboratory in casting T.N.T. into big common shell during 1913-14; but no service use for the explosive, other than as a fine powder for exploder bags, had been approved when the war began. Further research as to detonation had, however, produced a direct action fuse (No. 44) which was capable of bringing smaller natures of lyddite or T.N.T.-filled shell to complete detonation. This fuse was also provided with a safety device which prevented it from functioning until the "spin" of the projectile had released a shutter after the shell had left the muzzle of the gun. It was about to come into supply in the summer of 1914.

Thus in July, 1914, the actual use of T.N.T. for service purposes was still limited to the filling of exploder bags. Its early acceptance in warheads was contemplated. A means of bringing it to detonation existed for both larger and smaller natures of shell; but no graze fuse had been developed to facilitate the use either of picric acid or T.N.T. for certain important purposes in the field. Upon the outbreak of war, final trials to test the efficiency of T.N.T. as a substitute for

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[1] Sir F. Nathan to Lord Haldane, 1912.

[2] *Ordnance Board Report*, No. 15; HIST. REC./R/1320/6.

[3] *Research Department Report*, No. 6.

[4] *Ordnance Board Report*, No. 9, Appendix IX.

[5] *Ordnance Board Report*, No. 9. [6] S.R.C./182.

picric acid were hastened by the Ordnance Board, who recommended on 11 August, 1914, that it should be substituted for picric acid in the larger natures of H.E. shell and in the smaller natures as soon as the stock of picric acid had been exhausted. In natures above the 6-in. it should be used with fuse No. 45, a modification of fuse No. 18, introducing the safety shutter ; in smaller natures the same fuse should be adopted as for lyddite-filled shell.[1] Formal approval of these recommendations was given on behalf of the navy on 23 September, and of the army on 26 September.[2] In the meantime, however, active steps had been taken towards the actual use of the new explosive. On 12 August it had been accepted for naval mines in lieu of picric acid, which formed a dangerous freight for a mine-layer when brought to action.[3] On 29 August the Chief Superintendent of Ordnance Factories began filling larger natures of naval shell with it in anticipation of formal approval. The first 18-pdr. shells to be issued were loaded with it at Woolwich shortly after 11 September. These 18-pdr. shells were included in the first thousand rounds which were sent out to France on 19 October, 1914. For action upon graze, they were detonated by the conjunction of percussion fuse 44 with a time fuse (No. 80), an arrangement formally confirmed on 29 October.[4] The increased demand for naval mines created also a new requirement for T.N.T. during October, 1914. In fact, the intention was to replace all picric acid charges by T.N.T. and contractors were so informed during September, 1914.[5] This purpose was, however, frustrated by limitation in the supply.

In the manufacture of T.N.T., the chief processes of nitration are carried out in large cast-iron vessels. These are fitted with agitators for stirring the contents and with water and steam coils or jackets for regulating the temperature. The T.N.T. is then run off, washed with water to remove the acid, re-melted and purified either by means of alcohol or boiling water. Next it is dried in large iron vessels fitted with steam coils or by flowing slowly over a series of steam-jacketed steel trays.

When the decision to change over to T.N.T. was taken, nothing was known of British manufacturing capacity for the high grade explosive specified for service use. Manufacture was in fact limited to two or three firms, whose methods were slow and uneconomical, since they were intended to supply intermediate products for which a peace-time market existed for dyes. In particular, they used large quantities of oleum of which the supply was strictly limited, and the demand for other purposes, such as the manufacture of propulsive explosives, was considerable. The use of oleum was also a feature of methods of production in Germany, Spain and France, although the best continental methods were superior to the practice existing in British works, which was extremely wasteful of the basic raw material toluene.[6]

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[1] *Ordnance Board Minutes*, 10903.
[2] *Ibid.*, 11282.
[3] *Ibid.*, 11953.
[4] *Ordnance Board Minutes*, 11629.
[5] Contracts/A/2814.
[6] C.H.E. 1919, 2575.

During October, 1914, Dr. Hodgkinson, Professor of Chemistry at the Ordnance College, acted as expert adviser to the Director of Army Contracts on this subject.[1] At his suggestion the Research Department, Woolwich, undertook to manufacture three tons of T.N.T. a week. As no known process was satisfactory, the Department started systematic research on 18 October, 1914, improvising from existing experimental plant a semi-industrial plant on a three-ton scale, with the intention of nitrating M.N.T. to T.N.T. without the use of oleum. The immediate demand was so acute that this output was considered of great importance. The plant also became an important means of developing manufacturing methods and a training school for chemists and operatives. Further plant in the Department was improvised for re-crystallising crude T N.T. available from the dye-works of Messrs. Leitch & Company, and the Clayton Aniline Company. This plant, construction of which began on 2 December, 1914, supplied a large proportion of the pure T.N.T. used by the Chief Superintendent of Ordnance Factories in exploder bags for nearly a year. Work was also carried out on the concentration of waste acids in connection with the process of making T.N.T. without oleum.[2]

Regular output from the semi-industrial plant began on 17 January, 1915. A report[3] was made on 26 January on the process as then developed, subsequently known as R.D. Process No. 1. In its primary form it was a one-stage system for nitrating M.N.T. up to T.N.T. without the use of oleum. It included the regulation of temperature during nitration according to a fixed scheme which secured safety in manufacture. A special feature was the elimination of tri-nitro-toluene from waste acids by oncoming mono-nitro-toluene, a process afterwards known as detoluation. It was at least four times as rapid as the processes existing then.

A modification of R.D. Process No. 1 which was contrived shortly after 26 January, 1915, utilised for the production of mono-nitro-toluene the remaining strength of the sulphuric and nitric acid in the waste acids. This method had an additional advantage in avoiding the high prices then charged by the trade for mono-nitro-toluene. The original one-stage process for nitrating up from mono-nitro-toluene was thus changed into a two-stage cyclic process for making tri-nitro-toluene from toluene.[4]

Thus, by the end of January, 1915, the investigations effected by the Research Department had established a safe and efficient scheme of manufacture, which dispensed with the use of oleum and was far more economical of time and material than any previous practice. Production continued on the semi-industrial plant at Woolwich until May, 1915. . During these few months, the Research Department studied manufacturing conditions, evolving a second

[1] 74/H.E./4 ; *Ordnance Board Minutes* 11618. [2] S.R./12023/14.

[3] *Research Department Report on Process and Plant for making Trotyl without Oleum,* 26/1/15.

[4] *Second Report on Process for making Trotyl without the use of Oleum.* May, 1915.

method known as R.D. Process No. 2.[1] The process conserved sulphuric acid and approached the ideal theoretical method of production.[2]

A large amount of research into the details of the processes was carried out at the national T.N.T. factories established for the purpose of the war, particularly at Oldbury and Queen's Ferry.[3] Investigations at Oldbury evolved a counter-current process, starting at the one end with strong sulphuric acid and at the other with mono-nitro-toluene and emerging respectively as T.N.T. and spent acid, the nitric acid being fed into the plant at intermediate stages. The great advantage of this method, which was started at Oldbury in October, 1917, lay in its high capacity, which enabled a plant nominally built for 100 tons a week to produce 500.[4] Throughout the war, the experience gained in making T.N.T. on a large scale was utilised in the improvement of process and the development of economical methods in numerous technical details. Before the close of hostilities the intensive study given to T.N.T. production resulted in a standardisation of methods, which allowed only of the further introduction of comparatively minor refinements.[5]

(c) Adoption of Ammonium Nitrate Mixtures.

Thus, by the spring of 1915, an efficient and economical process for making T.N.T. had been evolved. During that year production was organised to the full extent of the country's capacity,[6] while subsequent experience and research advanced efficiency in government and trade factories. The Committee on High Explosives was formed on 13 November, 1914, under the chairmanship of Lord Moulton, for the express purpose of advising the War Office as to the supply of high explosives and particularly of their raw materials.[7] Within a few days Lord Moulton, basing his notion of the demand upon the known enormous expenditure of high explosives by the enemy, concluded that the whole amount of picric acid and T.N.T. which could be obtained from the raw materials available would be utterly insufficient for the purposes of the war.[8] During the next two years, in the interests of supply, he urged upon the military authorities the adoption of mixed explosives, in which varying proportions of ammonium nitrate were used with T.N.T., for the purpose of economising toluol. A strong body of official military opinion was at this time opposed to the introduction of a new explosive or a novel system of filling at that stage of the war.[9] Expert artillerists realised to the full that lengthy and exhaustive investigation would be needed before alternative explosives could be introduced as bursting charges with any certainty of safety or efficiency.[10] The

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[1] *Research Department Second Report on Process and Plant.*

[2] Hist. Rec./R/1500/14, p. 107. [3] Hist. Rec./R/1500/14, p. 94.

[4] Hist. Rec./R/1500/14, p. 107.

[5] Dr. Farmer to Lord Moulton (18/8/18), X236/55.

[6] See below, pp. 46-49, 54-59. [7] 74/H.E./4. [8] Hist. Rec./R/1500/7.

[9] *Ordnance Board Minutes* 12302.

[10] Director of Artillery, January, 1915 (74/H.E./25); M.G.O., February, 1915 (74/H.E.A./8).

Secretary of State, Lord Kitchener, was, however, willing and anxious that investigation should be made, partly to safeguard British supply in the event of the failure of picric acid and T.N.T.,[1] partly to enable the Government to satisfy the expectation of the Allies who were clamouring for aid from the productive capacity of Great Britain.[2] He therefore authorised Lord Moulton on 13 February, 1915, to produce every form and kind of explosive that could be made in England.[3] The practical difficulties entailed in introducing new types of explosive were overcome step by step at the reiterated instance of Lord Moulton, as is described below. Not only were mixed explosives substituted for straight T.N.T. in British military service, but the comparative dependence of certain of the Allies, such as Italy, Russia and Portugal, on British production enabled Lord Kitchener and Lord Moulton to insist upon their economising T.N.T. by the adoption of ammonium nitrate mixtures.[4]

The first mixture seriously considered was ammonal, which was already produced by a British firm—Roburite and Ammonal, Ltd. It was known to be used by the Austrian and German Governments for filling smaller natures of shells. It had been largely used in the Balkan War. It contained 65 parts of ammonium nitrate, 15 parts of T.N.T., 17 parts of aluminium powder and the rest charcoal.[5] Its use would, therefore, effect a very considerable saving of T.N.T., which could, moreover, be used in the crude commercial form, thus avoiding the tedious and difficult processes of purification.[6]

On 27 November, 1914, Lord Moulton drew up a memorandum[7] on the immediate shortage of high explosives, suggesting the use of alternatives, viz., Schneiderite and ammonal. The seriousness of the position in regard to the supply of raw materials for T.N.T. was again represented by Sir R. Sothern Holland on 9 December,[8] and on the following day the Ordnance Board was requested to consider the use of ammonal in high explosive shell in view of the existing supply difficulties.[9] The Board had previously made certain investigations in 1908, and had then concluded that the keeping qualities of ammonal were not free from suspicion. Action had, therefore, been suspended in view of better results expected from picric acid and T.N.T.[10] The trials which had then taken place were in armour-piercing shells with a base-fuse. The Board reported adversely on the explosive on 14 December. A serious disadvantage was the insensitiveness due to setback, of which the results were uncertain. It was understood that Krupps had found that detonation had thereby been prevented. The problem of detonation would be more serious with a nose-fuse than a base-fuse. The explosive was less violent than T.N.T. Lengthy trials would be

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[1] *Ordnance Board Minutes* 12302. [2] HIST. REC./R/1520/8.

[3] HIST. REC./R/1501/1. [4] HIST. REC./R/1501/1 (30/7/15; 1/4/16).

[5] 74/R/8. 50.

[6] Meetings of Committee on High Explosives, 16, 18 November, 1914, (74/H.E./40).

[7] HIST. REC./R/1520/8. [8] 74/H.E./4. [9] *Ordnance Board Minutes* 11989.

[10] *Ordnance Board Minutes* 559, 2380; *Ordnance Board Report*, No. 9 (1908), p. 14.

needed before the Board could recommend its use. Its manufacture might encroach on the supply of acid for other explosives.[1] During the next two months, the use of Schneiderite was investigated for shell filling; but ammonal was successfully tried for engineering purposes at the front and Lord Moulton took steps to produce it in quantity.[2] It was also adopted immediately as a bursting charge for trench warfare purposes in certain trench mortar bombs and in hand grenades.[3]

Early in February, 1915, Lord Moulton again urged the Master-General of Ordnance (General von Donop) to accept ammonal in high explosive shell, asserting that the change was of the highest importance to the Allied armies. No other explosives of equal value could be supplied for gun ammunition without restricting the output of other service explosives. Existing arrangements for purchasing ammonium nitrate from outside sources would prevent encroachment upon acid supplies. The main defect of an ammonium nitrate mixture, viz., its hygroscopicity, would only be serious in the case of long storage. General von Donop accordingly gave instructions for the trial of ammonal in shells on 11 February, 1915, in case the supply of picric acid and T.N.T. should be insufficient. At the same time he stated his opinion that it was undesirable to introduce new explosives without full trials, but that this did not mean that trials should not be carried out with despatch.[4]

It was pointed out by the Superintendent of Research on 15 February, 1915, that the best method of overcoming "setback" was either to press the explosive into the shell or to fill it in blocks. The method would depend on the plant available at the Royal Laboratory.[5] It had, however, been agreed on 7 January, 1915 at a meeting summoned by Lord Moulton to discuss the use of alternative explosives that someone other than the Ordnance Factory should carry out filling operations if any new explosive were introduced.[6] The Chief Superintendent of Ordnance Factories pointed out on 7 March that block-filling with ammonal would be feasible not only in straight-walled 18-pdr. shell, but also in those new designs of Land Service shell which had base-adapters. Trials were, therefore, arranged on 8 March with ammonal stemmed into 4-in. H.E. shell detonated with fuse No. 17 with and without a gaine and with fuse No. 44.[7] These experimental 4-in. shell were finally despatched for trial by the Chief Superintendent of Ordnance Factories about 21 June, 1915. The Board reported on 29 June that setback was considerable and that failures with the No. 44 fuse were doubtless due to this cause as a gaine would be needed for nose-fused shell stemmed with ammonal.[8] In the meantime, experiments with amatol had met with greater success and ammonal was not considered further for artillery purposes, although it continued to be used for trench warfare until the shortage of aluminium led to its supersession by amatol in grenades and trench mortar ammunition during the earlier part of 1917.

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[1] *Ordnance Board Minutes* 11989.
[2] Lord Moulton's Unregistered Memo. *circa.*, 19/12/14. [3] 74/H.E.A./8.
[4] *Ibid.* [5] *Ordnance Board Minutes* 13004. [6] 74/H.E./25.
[7] *Ordnance Board Minutes* 13004. [8] *Ordnance Board Minutes* 14321, 14457.

Amatol was evolved as a result of investigations into the practicability of adopting a standard French explosive, viz., Schneiderite, a mixture of ammonium nitrate and di-nitro-naphthalene, which was in common use as a blasting explosive in French mines. Close contact with French experts had been established during the autumn of 1914 and information had been obtained as to the design of high explosive shell generally and the nature of the filling in particular. Other Allied armies, *e.g.*, the Serbians, were prepared to use Schneiderite, which had been tested in the Balkan war.[1] A British commission visited France and reported to Lord Kitchener shortly before 17 December, 1914, on the methods used at the Creusot works in economising T.N.T. by filling shell with " Schneiderite tolite " composed of 40 per cent. T.N.T. and 60 per cent. of Schneiderite in the form of compressed pellets. Although the introduction of the new explosive entailed considerable changes in the methods of filling and means of detonation, Lord Kitchener gave instructions for experiments about 17th December, 1914, in view of the shortage of picric acid and T.N.T.[2]

During January, 1915, Lord Moulton made preliminary arrangements for the manufacture of di-nitro-naphthalene with the Explosives Chemical Ltd. at Great Oakley. Curtis's and Harvey undertook to prepare the Schneiderite tolite in their gunpowder mills at Faversham and to instal hydraulic plant for compressing the pellets.[3] On 21 January, Lord Kitchener gave instructions that samples of British-made Schneiderite should be tested[4] and trials of the explosive made by Curtis's and Harvey were carried out in 12-pdr. shell. From these it was concluded that Schneiderite tolite was suitable for small natures. On 24 February, a report having been received on French methods of filling,[5] experiments in filling 18-pdr. and 13-pdr. shell and fusing them with the 80/44 fuse and gaine were carried out by the Research Department. It was found that the length of the gaine would reduce the amount of Schneiderite to a very small proportion of the whole mixture.[6] This was composed as follows :—

	Percentage.
Ammonium Nitrate	52·5
Di-nitro-naphthalene	7·5
T.N.T.	40·0

The use of di-nitro-naphthalene in France was obviously due to its local manufacture. The Research Department attempted to replace it by increasing the proportion of T.N.T., which would increase the explosive power, since di-nitro-naphthalene was little more than a fuel undergoing combustion by the ammonium nitrate. Trials at rest with equal parts of ammonium nitrate and T.N.T. gave good results on 8 March, 1915. Two days later the Department proposed the use of this simple mixture of ammonium nitrate and T.N.T. in preference to Schneiderite.[7] In view of these suggestions and of the difficulty

[1] HIST. REC./R/1520/8.
[2] *Ordnance Board Minutes* 12302.
[3] 74/H.E.A./19.
[4] HIST. REC./R/1501/1.
[5] HIST. REC./R/1501/1 (13/2/15).
[6] *Ordnance Board Minutes* 12777, 13179, 13264.
[7] HIST. REC./H/1520/6, p. 3.

already experienced in filling with Schneiderite any further trial of the French explosive was abandoned on 19 March, 1915.[1]

On that day, after testing mixtures of ammonium nitrate and T.N.T. in various proportions, the Research Department recommended the use of 55 per cent. ammonium nitrate with 45 per cent. T.N.T.,[2] further suggesting, on 13 March, that crude T.N.T. should be used to avoid the difficulties of purification.[3] In a memorandum[4] on the position as to high explosives, submitted to the Munitions of War Committee on 13 April, Lord Moulton urged the immediate adoption of the new mixture in order to economise T.N.T. and avoid the need for its purification, a difficult and dangerous operation calculated to reduce output.[5] In view of the urgency of the question, the Ordnance Board recommended the use of this 45/55 mixture for smaller natures of Land Service shell (6 in. and under) on 15 April, without awaiting tests of the practicability of filling on a large scale.[6] Shortly afterwards the Chief Superintendent of Ordnance Factories reported that the " porridge " of which the mixture consisted when hot was too stiff to be poured, as was the practice with T.N.T. or picric acid.[7] To meet this difficulty the proportion of ammonium nitrate was reduced to 40 per cent., and approval was given on 11 May, 1915, for the filling of all Land Service shell up to 6 in. with a 40/60 mixture.[8] It had already been decided on 27 April that the hygroscopicity of ammonium nitrate would make any mixture of which it was an ingredient unsuitable for naval use, while uncertainty as to the general stability of the mixture made its adoption for naval shells undesirable.[9] Picric acid was, therefore, retained for naval 6-in. shell until enough T.N.T. should be available. The actual use of 40/60 for the small natures of Land Service shell was delayed pending the adaptation of the filling plant at Woolwich.[10]

By the end of June the filling plant had been modified and could be used satisfactorily though it was not ideal. The Chief Superintendent of Ordnance Factories began to change over from T.N.T. to 40/60 amatol in 18-pdr. shell at this time,[11] only using T.N.T. in block form for a certain proportion of this nature during the autumn of 1915.[12]

In the meantime, approval was given for the use of amatol 40/60 in other projectiles. It was approved as a filling for trench mortar ammunition on 25 May, 1915 ;[13] but ammonal was chiefly used for this purpose until 1917. The use of amatol 40/60 instead of gun-cotton in torpedo warheads was recommended on 8 June, 1915. It was adopted for aircraft bombs by the navy on 15 July, 1915,[14] and by the army on 23 July.[15]

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1 *Ordnance Board Minutes* 13264.
2 *Ordnance Board Minutes* 13200.
3 *Ibid.*, 13332.
4 Hist. Rec./R/1500/2.
5 74/H.E./197.
6 *Ordnance Board Minutes* 13504.
7 *Ibid.*, 13563.
8 Enclosure to 74/H.E.A./19.
9 74/H.E./197.
10 *Ibid.*
11 *Ordnance Board Minutes* 16242 ; 74/H.E.T./92.
12 *Ordnance Board Minutes*, 17316.
13 74/H.E.A./19 ; *Ordnance Board Minutes* 14094.
14 74/H.E.A./19.
15 *Ordnance Board Minutes* 15157.

The supply authorities continued to press for sanction to use 40/60 in larger as well as smaller natures of shell. In accordance with a verbal ruling given by the Director of Artillery on 11 August, 1915, the Chief Superintendent of Ordnance Factories began to use either this mixture or picric acid in 12-in. howitzer shell for Land Service, as was most convenient. A similar practice was recommended by the Ordnance Board for 8-in. and 9·2-in. Land Service shell on the day following. T.N.T. was, however, to be preferred to picric acid for these natures when it was available.[1] Accordingly, the Chief Superintendent of Ordnance Factories filled these shell also with picric acid or 40/60 amatol as was convenient. Formal approval of the alternative use of 40/60 in these larger natures of howitzer shell was given on 18 August ;[2] and was subsequently extended on 10 October to 9·2-in. gun ammunition.[3]

Thus by November, 1915, amatol 40/60 was in actual use in the Royal Laboratory in all natures of Land Service shell. In the larger natures it was used alternatively with picric acid. In 13-pdr. and 15-pdr. shell it was the only filling used. For naval service it had only been adopted for 15-in. howitzer shells, the remaining natures for naval service being filled either with picric acid or T.N.T. according to the method of detonation available.[4] The most important change had, however, been effected in the 18-pdr. shells for Land Service. In addition to T.N.T. used in blocks these were filled with 40/60 amatol by contractors who had melt plant ; at the Royal Laboratory, a large proportion was filled with 40/60 mixture on the existing melt plant, others with an amatol containing a higher percentage of ammonium nitrate, viz., 80/20, either in blocks or pressed direct into the shell[5] on a few presses which had been recently obtained.[6]

Subsequent investigation made possible the use of mixtures intermediate between 40/60 and 80/20. It was found that 50/50 could be poured if attention were given to the dryness of the ammonium nitrate,[7] and it was sanctioned as an alternative to 40/60 about February, 1917.[8] Later experiments led to the approval of 60/40 as a poured filling on 2 July, 1918,[9] and even to filling with 70/30 as a semi-solid, a mixture approved in 18-pdr. and larger shells in and after April, 1918.[10]

The earliest experiments with an 80/20 mixture had been carried out by the Research Department during April, 1915. Two methods of filling were then tested—viz., block-filling and hand-stemming. In both the explosive was first used warm and plastic. Subsequent firing trials with No. 18 fuse proved that 80/20 by warm or cold mixing was a satisfactory explosive for filling 18-pdr.[11] Steps were taken during May to utilise the heavy gunpowder mills and

[1] *Ordnance Board Minutes* 15086.
[2] *Ibid.*, 15604.
[3] *Ibid.*, 16725.
[4] *Ibid.*, 17316.
[5] *Ibid.*, 17316.
[6] *Ibid.*, 16791.
[7] HIST. REC./R/1500/14, p. 186.
[8] *Ordnance Committee Minutes* 13665a ; cf. HIST. REC./R/1500/14, p. 186.
[9] *Ibid.*, 30091.
[10] *Ibid.*, 29047, 33420.
[11] *Ordnance Board Minutes* 13816, 13994.

Schneiderite presses at Curtis's and Harvey's Faversham works for incorporating the amatol, and pressing it into blocks. Owing to local conditions the firm was unable to handle shell in the required numbers. They therefore undertook to manufacture blocks for insertion into shell at the Royal Laboratory.[1] Difficulty having been experienced in obtaining well-formed charges with a warm mixture, the Research Department evolved on 8 May, 1915, a method of pressing the blocks cold, which became the standard process for block-filling.[2] During the summer, the Faversham works began turning out blocks by the cold process at 40,000 weekly, using both the hydraulic Schneiderite presses and also the lighter cam presses employed normally in making pellets of blasting gunpowder. By October, 1915, they were supplying the Ordnance Factory with 100,000 charges weekly.[3] A second firm, the Explosives Loading Company, who had already made T.N.T. in blocks, at first undertook to cast 40/60 in blocks for 18-pdr. in order to avoid the delay entailed in installing heavy presses.[4] Later, about October, 1915, they arranged to make blocks of 80/20 for this nature[5].

In the meantime, the Research Department had evolved a one press method of filling cold 80/20 direct into 18-pdr. shell, and in July, 1915, the Chief Superintendent of Ordnance Factories was arranging to install presses for this purpose with the intention of using this system when shells were available, and otherwise pressing blocks, coating them with paraffin and storing them.[6] This one-press method was adopted in order to avoid the hand-stemming entailed in the French process, whereby small quantities of the powdered explosive were stemmed into the shell cold with a wooden drift and mallet to the required density.[7] By November, 1915, 36,000 18-pdr. shell were being filled weekly at the Royal Laboratory by the one-press method.[8]

By the end of November, 1915, 80/20 was in actual use in a considerable proportion of 13-pdr. and 18-pdr. straight-walled H.E. shells. Supply authorities continued throughout the year to urge still further economy in T.N.T. by extending the sanction for 80/20 to larger natures, particularly for the increased shell programme to which the Minister of Munitions was working. The Chief Superintendent of Ordnance Factories was asked on 30 July to consider designs of larger natures of shell which should be suitable for block-filling.[9] By 17 August, it was definitely agreed by supply authorities that 80/20 would have to be used in a large proportion of projectiles.[10]

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[1] *Ordnance Board Minutes* 14342.

[2] An account in detail of the work of Research Department in connection with these mixtures is given in Hist. Rec./H/1520/6.

[3] Hist. Rec./H/1520/6, p. 11. [4] *Ordnance Board Minutes* 13816 II.

[5] *Ordnance Board Annual Report*, 1915, p. 194.

[6] *Ordnance Board Minutes* 14660 I.

[7] *Ordnance Board Annual Report*, 1915, p. 202.

[8] Hist. Rec./H/1520/6, p. 10. [9] *Ordnance Board Minutes* 14935.

[10] *Ibid.*, 16164. See below, p. 72.

Immediately afterwards, the practicability of adopting this course was shaken by unsatisfactory results obtained with 80/20 in conjunction with the No. 100 fuse and the No. 1 gaine.[1]

This graze fuse (No. 100) had only just come into supply.[2] The earlier experiments with amatol had been carried out either with a direct action fuse (No. 18) or with a time fuse (No. 80) and gaine. The gaine had already come into service use with the double fuse, No. 80/44, which had been adopted as an improvised fuse to act upon graze in October, 1914. Prematures in 18-pdr. ammunition were ascribed in July and August, 1915, to the breaking of the gaine.[3] During the next six months the whole system of detonation for H.E. shell was under review, and on 7 September, 1915, the Ordnance Board suspended further trials with 80/20 amatol until a satisfactory gaine should have been obtained.[4]

During July, 1915, experiments had already been made with a view to strengthening the detonative system for 80/20 by means of a 10 grain detonator in the upper chamber of the gaine, an arrangement also calculated to economise tetryl of which supply was short.[5] Continuous investigation as to the causes of prematures which were reported during the autumn of 1915 led to the adoption of a shortened gaine, a manufacturing design for which was approved on 10 November, 1915.[6] In order to obtain complete detonation with so insensitive an explosive as 80/20 (block) amatol, a 10-grain fulminate detonator was introduced into the gaine and trials of 10,000 18-pdr. shell filled with 80/20 amatol blocks and fitted with No. 100 fuses and the shortened detonator gaine were carried out towards the end of November.[7]

Prematures and blinds with H.E. ammunition were constantly reported from France at this time. The use of amatol was one of the causes to which the army attributed the high proportion of blinds.[8] It was admitted in November, 1915, that the question of density, and particularly the effects of set-back had prevented both the French and Austrian Governments from adopting ammonium nitrate mixtures in their heavier shells—and that there was still urgent need for investigating the question of detonation.[9] Already (September, 1915), it was estimated that the 1916 requirements depended upon the use of at least a small proportion of 80/20 amatol, and that the increases anticipated in 1917 could only be met by using it extensively. Supply officers considered that adaptability and a definite constructive policy in regard to the use of substitutes were essential for the fulfilment of the enormously augmented demand. Early decisions and helpful constructive criticism in the case of an adverse decision were needed. It was suggested that for this purpose, the Research Department, which had already done admirable work, should be greatly enlarged, and that the whole system of obtaining official sanction for the use of a particular explosive should be controlled by the Ministry.[10]

1 *Ordnance Board Minutes* 15214.
2 HIST. REC./R/1122.11/16.
3 *Ordnance Board Minutes* 15532.
4 *Ordnance Board Annual Report*, 1915, p. 203.
5 *Ibid.*, p. 170.
6 *Ibid.*, p. 176.
7 *Ibid.*, p. 178.
8 *Ordnance Board Minutes* 16960.
9 D.D.G. (A) 9671.
10 X235/166.

The Department of Design was established within the Ministry for the primary purpose of improving high explosive ammunition and fuses early in December, 1915.[1] By the following February, an improved fuse and gaine system had been evolved.[2] This included fuse No. 101, a modification of fuse No. 100, with a shortened and modified magazine gaine (No. 2 Mark II) filled with tetryl and brought into close contact with an exploder bag containing T.N.T.[3] Satisfactory trials of this system with 80/20 amatol were held on 14 March, 1916.[4] The conditions necessary for complete and safe detonation of 80/20 were thus obtained; but it remained to put them into effect.[5] Schemes for a method of filling had meanwhile passed through many vicissitudes. One section of a British mission appointed by Mr. Lloyd George, which investigated French explosives and methods of filling in October, 1915, had recommended that[6] all calibres should be filled by pressing charges direct into shell from the nose. The members of this section put forward no definite recommendation for adopting any new explosive, but recorded their impression that in France "great energy and intelligence were displayed in making every possible use of all kinds of high explosive which could be obtained. A shortage in any one led to the immediate use of substitutes, if they could not have sufficient of the best, the next best was utilised; experiments are continually in progress with a view to broadening the basis of supply and making special mixtures to suit different methods of filling varying sizes of shell."

A definite decision as to the adoption of 80/20 and the form in which it should be used was then becoming urgent in order to determine the lay-out of new filling factories and with a view to economy in the supply of T.N.T. By September, 1915, it was clear that a decision in favour of adopting 80/20 for all calibres was necessary in order to meet a small part of the 1916 programme and the large increases anticipated in the 1917 programme.[7] New filling factories, such as Chilwell, intended for the larger natures had been planned at first for block-filling with 80/20.[8] At a conference held by the Minister with the representatives of the supply departments concerned on 30 September, it was, however, decided to double the melt-filling capacity in order to allow for the use of 40/60, should 80/20 prove unsatisfactory.[9] The report of the mission to France led to a change in plan. Chilwell, was laid out for pressing 80/20 direct into the shell by Lord Chetwynd, who had been a member of the mission; but artillerists still hesitated to sanction the use of so high a proportion of ammonium nitrate while the method of detonation was uncertain.

Accordingly, both at Chilwell and at the other National Filling Factories, arrangements were made in accordance with the decision of 30 September, for the use of 40/60 melt until 80/20 should be approved,

[1] HIST. REC./R/800/1, p. 2.
[2] For the details of the investigation see HIST. REC./H/1520/6.
[3] 74/H.E.A./142.
[4] *Ordnance Committee Minutes* 1402.
[5] 74/H.E A./142.
[6] HIST. REC./R/1340/10.
[7] HIST. REC./R/1500/5.
[8] *Ibid.*, 1122.3/48.
[9] D.M.R.S./212.

although this entailed a reduplication of plant. On 28 October, 1915, the Chief Superintendent of Ordnance Factories also pointed out that an entire change to 80/20 for all H.E. shell would render useless all the filling plant at the Royal Laboratory except three 80/20 presses.[1] Trials with block-filled 6-in. shells were again ordered at the instance of the Director General of Munitions Supply on 23 November, 1915[2]; but these were carried out on 22 and 23 January, 1916, with unsatisfactory results.[3] In the meantime, a process for mixing 80/20 and a method of pressing it into large shells, based upon French experience, had been devised in the experimental shops at Chilwell, and the results of trials of these shells at the end of January, 1916, were extremely satisfactory.[4]

Bulk filling of large shell with pressed 80/20 began at Chilwell on 19 April, 1916,[5] and this factory provided the greater part of the heavy ammunition for the 1916 campaign, which was filled either with 40/60 on the melt plant or with pressed 80/20. The other new filling factories started up with amatol mixtures at various dates through the summer, beginning with their melt (40/60) plant.[6] The change in the design of graze fuse and gaine gave rise to considerable delays in manufacture during the spring of 1916.[7] Further delay occurred in the production of metal exploder containers, which had been proved essential to good detonation of 80/20 in the larger natures.[8] The management and operatives of the National Filling Factories were new to their work. It was clear that the important conditions necessary to success were not being put into practice even so far as was possible pending the production of the new fuse. For example, sufficient care was not being used to ensure close contact between the gaine and the exploder bag in large numbers of shell. From the evidence of experiments it was apparent in May, 1916, that if inferior results were obtained they were due to the ineffectiveness of the fuses and gaines or to the method of filling. Nevertheless there was a tendency to construe the reports of failures which were still received from the front as indications of the unsatisfactory character of 80/20 amatol as a bursting charge for shells.[9] Its use was retained and extended in the face of considerable opposition and at the constant instance of the supply authorities,[10] who at the same time used every effort to improve the methods of filling.

The remedy was gradual and it was not until defects in fuses and gaines had been eliminated and methods of filling improved that the true value of 80/20 amatol as an explosive was justly realised. Detailed investigation and careful control of factory practice combined with a tightening up of inspection during the years 1916 and 1917 eventually secured an immense improvement in all the components of the detonative system.[11] Improved methods, worked out contemporaneously in the National Filling Factories, had a similar effect as regarded the

1 *Ordnance Board Minutes* 16791.
2 *Ibid.*, 17151.
3 *Ordnance Committee Minutes* 835.
4 HIST. REC./R/1122.3/48.
5 HIST. REC./H/1520/6.
6 HIST. REC./H/1520/8.
7 HIST. REC./H/1320/1, pp. 13-14.
8 HIST. REC./H/1520/5; 74/H.E./1257.
9 74/H.E.A./142.
10 HIST. REC./H/1520/5.
11 HIST. REC./R/1320/10.

actual loading of the shell. A method of hot-filling with 80/20 amatol, evolved at the Georgetown Factory at the end of July, 1916, was approved for service use on 19 December, 1916, and introduced gradually into the filling factories as a means of converting the 40/60 melt plant to 80/20. Screw-filling plant was installed during the first few months both for hot and cold 80/20 amatol.[1] From the end of 1916 onwards, the proof shells from the various factories began one by one to give first-class results.[2]

Methods of testing the efficiency of amatol had also improved. One of the problems in its introduction had been the absence of smoke, which made ranging from the air difficult and deprived artillerists of one of the means by which they had been wont to judge effective detonation at proof.[3] Investigations as to a satisfactory method of producing smoke began in June, 1915. Red phosphorus, the material used in France and Germany, was discarded on account of risk of premature due to its instabilising effect on the explosive.[4] Several smoke mixtures were evolved and inserted locally in the shell, in boxes or bags but not distributed throughout the filling. Eventually, smoke mixture No. 5, one of a series evolved at the Research Department, gave a smoke result with 80/20 superior to that of T.N.T.[5] At the same time, the introduction of mechanical methods of testing fragmentation by "jump cards" had provided an accurate means of recording the results of trials apart from the "eye and ear" observation upon which entire reliance had previously been placed.[6]

While these improved conditions were contributing to bring 80/20 amatol into favour, difficulty was experienced with 40/60 amatol owing to its particular tendency to "spewing" or "creeping" in the shell in high temperatures when crude T.N.T. of low setting-point was used in its composition.[7] Thus it was agreed about September, 1916, that only purified T.N.T. should be used in 40/60 amatol for the East or the Mediterranean,[8] and it was found that 80/20 was not subject to exudation and that it was in consequence superior in this respect to 40/60 made from crude T.N.T.[9]

Comparison of the results of proof showed a distinct superiority in lyddite-filled shell during the latter part of 1916, while the results obtained with 80/20 were considerably inferior to those with 40/60. From December, 1916, the quality of the 80/20 shell rose steadily, equalling those with 40/60 by the end of the year. All types of amatol-filled shell thenceforward tended to reach the level of quality shown by picric acid, until September, 1917, when a steady and even level of efficiency was revealed by proof results and maintained with all three explosives.[10]

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[1] Hist. Rec./H/1520/8.
[2] *Ibid.*
[3] *Ordnance Board Annual Report*, 1915, pp. 182-4; Hist. Rec./H/1520/8.
[4] *Ordnance Board Annual Report*, loc. cit.
[5] Hist. Rec./H/1520/6.
[6] Hist. Rec./H/1520/6.
[7] *Research Department Report* 31.
[8] Hist. Rec./R/1520/5, p. 3.
[9] *Ibid.*, 1500/14, p. 186.
[10] M.C./372.

(d) USE OF AMMONIUM PERCHLORATE MIXTURES.

Among the explosives first considered as substitutes for T.N.T. in 1914 were ammonium perchlorate mixtures, a form of explosive used very largely in France during the war. The main defect of the perchlorate mixtures first investigated was a high degree of sensitiveness. In particular, they were readily ignited by rifle and bullet fire. They were therefore definitely rejected as unsuitable for gun ammunition in April, 1915.[1] The Research Department, Woolwich, had, however, investigated various ammonium perchlorate mixtures and had evolved a mixture known as Composition No. 30, a modification of megadyne, which was accepted for naval mines at a conference held in Lord Kitchener's room shortly before 28 November, 1914.[2] "Blastine" (a mixture of ammonium perchlorate, nitrate of soda and D.N.T.) was sanctioned for use for Trench Warfare purposes and naval mines, but was in fact reserved for the latter[3] and used in very limited quantities. Composition B was subsequently introduced as an alternative to Composition No. 30 in mines in order to economise aluminium, an essential ingredient of No. 30.[4] The Ministry of Munitions was faced in the autumn of 1917 with the problem of meeting a programme which nearly doubled the output of high explosives and suggested that the requirements might be met by using in naval mines a large proportion of mixtures containing ammonium perchlorate and also by adopting this explosive for aerial bombs.[5]

The use of Composition B in aerial bombs was rejected early in March, 1918, owing to the sensitiveness of the mixture to rifle bullets and its inflammability, and its use in mines was likewise restricted. Moreover, it was agreed that the development of a design of naval mine to take a large enough charge of an ammonium perchlorate explosive would take too long to make any difference to the 1918 programme.[6] A series of investigations was subsequently made at Porton by the Chief chemist (Dr. Farmer) and showed that a mixture containing ammonium chloride in addition to ammonium perchlorate and other substances was even less sensitive than amatol 80/20 to rifle-bullet fire. Experiments as to the conditions of use were subsequently continued by the Research Department, Woolwich, and were still in progress at the close of the war.[7]

(e) ABANDONMENT OF PICRIC ACID.

During the summer of 1916 there was a strong reaction in favour of picric acid, particularly in the larger natures of shell; but this opinion was gradually modified with practical experience of the improved quality of amatol-filled shell.[8] By the end of 1917 about 66 per cent. of the Land Service shells were being filled with 80/20 and the use of 40/60 or 50/50 in the remainder was about to be abandoned. Amatol 80/20 was in use for all the smaller sizes of aerial

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[1] *Ordnance Board Minutes* 12016; cf. *ibid.*, 13371.
[2] *Ibid.*, 12016.
[3] X235/20.
[4] HIST. REC./R/1500/14, p. 192.
[5] D.M.R.S./505A1.
[6] X237/23.
[7] HIST. REC./R/1500/14, p. 194; X/H.E.A./350.
[8] 74/H.E.P./193.

bombs and was about to replace 40/60 in the 230-lb. bombs for Land Service. Practically all trench warfare bombs and grenades were being filled with 80/20. The Admiralty was using no 80/20 at all, but certain naval shells were being filled with picric acid and the remainder with Grade II T.N.T. Amatol 40/60 had just been accepted as a substitute in these and was the established filling for mines and depth charges. In certain naval shell, such as the larger sizes of armour-piercing shell, the use of picric acid in admixture with ni-nitro-phenol was sanctioned early in November, 1917, as a means of ensuring a delay in detonation.[1] Enormous demands for T.N.T. for destructors were formulated by the Admiralty at the end of that year, when the whole question of explosives supply was specially subjected to difficulties arising from the restrictions in tonnage. Accordingly an Explosives and Chemicals Allocation Sub-Committee of the War Priority Committee was formed in December, 1917, and arrangements were made whereby T.N.T. was provided for the destructors; but the Admiralty undertook to consider sympathetically the use of 80/20 and perchlorate mixtures. Eventually, 40/60 was, however, retained in depth-charges in view of its ascertained superiority for anti-submarine purposes.[2]

Early in December, 1917, the Ordnance Committee recorded that "the quality of the detonations of the three fillings lyddite, 40/60 and 80/20 are now practically equal and very satisfactory."[3] It was then recognised that there was little to choose between the effectiveness of these three explosives, except that 80/20 had certain practical advantages. Its power was the greatest; its insensitiveness rendered it safer than picric acid both in the gun and when stored; detonation of filled shells when struck by a projectile seldom spread, whereas with picric acid the detonation of one shell usually involved the whole dump.[4] The chief properties affecting the desirability of using different explosives are their stability, insensitiveness to a blow or a rifle bullet and their power. The table which follows denotes the degrees in which these qualities were ascertained to be present in the various high explosives towards the close of the war[5]:—

Explosive.	*Stability.*	*Insensitiveness.*	*Power.*
Picric acid ..	Good	100 (standard)	100 (standard)
T.N.T. (pure) ..	Good	115	95-99
Amatol (40/60)	Good, unless ammonium nitrate is impure.	120	112
Amatol (80/20)	Good	120	127
Ammonal ..	Good, unless T.N.T. impure.	115	158
Ammonium perchlorate mixture, viz., "No. 30."	Good	115-140	130

[1] 74/H.E.D./28. [2] X237/23. [3] *Ordnance Committee Minutes* 23347.
[4] Hist. Rec./R/1520/11. [5] Hist. Rec./R/1500/14, p. 198.

It was further calculated at the end of 1917 that Amatol 80/20 had very great advantages in respect of its cheapness and the tonnage of raw materials required for its production. The relative advantages of the three explosives in these respects were estimated in November, 1917, as follows[1] :—

Explosive.	*Tonnage of imports to produce one ton of explosive.*	*Cost of production per lb.*
Picric acid	7 tons	1s. 11d.
T.N.T.	4·5 ,,	1s. 3d.
Amatol (80/20)	2·2 ,,	7d.

Accordingly, in January, 1918, it was definitely decided to withdraw picric acid from use in all natures except armour-piercing or anti-concrete shell, for which no suitable system of detonating T.N.T. existed.[2] This was effected gradually and should have been finally completed during the last quarter of 1918.

Thus, when the war concluded, the explosive upon which entire reliance had at first been placed was about to be definitely abandoned. Great Britain had adopted in its stead ammonium nitrate mixtures and, in a lesser degree, straight T.N.T., as the basis for her high explosive programme, being justified in this respect by her command of toluol and ammonia. France, less rich in these materials, still relied upon picric acid, treating T.N.T. as a supplementary explosive. The United States, guided by British experience had adopted amatol except for shells of French design. Italy, urged to economise by British authorities upon whom she depended for a large part of her explosive supplies, was gradually replacing straight T.N.T. by more economical mixtures during the year 1918.[3]

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[1] Sir Keith Price to Sir Vincent Raven, 29/11/17.

[2] 74/H.E.P./193.

[3] M.C. 372; 74/H.E.P./193, HIST. REC./R/1501/3.

CHAPTER II.

ORGANISATION FOR THE SUPPLY OF EXPLOSIVES.

I. Normal arrangements for Explosive Supply.

At the outbreak of war, the Admiralty and the War Office were respectively responsible for the supply of propellants for the navy and the army, placing separate orders with the trade and sharing the output of the one national factory, the Royal Gunpowder Factory at Waltham Abbey, which was controlled by the Secretary of State for War through the Superintendent of Waltham and Enfield. Each department had its own system of accounting and inspection. Storage was the concern of Superintendent of Ordnance Stores for the navy, of Deputy Director of Ordnance Stores for the army.

In respect to high explosives, there obtained a different arrangement,[1] dating from 1907, when as a matter of convenience, the Chief Superintendent of Ordnance Factories had taken over the large stocks of picric acid, picric powder and gun-cotton which remained at the close of the South African War. High explosives were regarded as raw materials to be utilised in the Royal Laboratory, and the Chief Superintendent of Ordnance Factories was the authority for storage, accounting, and sentencing. No national high explosive factory existed, although Waltham Abbey made tetryl in small quantities. The position in regard to requirements and the stock to be held was reviewed biennially by representatives of the two services[2] and purchases were made for the Chief Superintendent of Ordnance Factories by the Contracts Department of the War Office.

The supply of raw material for explosive manufacture was in peace time the sole concern of the contractors. The Royal Gunpowder Factory, however, held certain national reserves of acetone, primarily for its own use and mainly on behalf of the Admiralty.

II. Reorganisation to meet the need for High Explosives.

(October, 1914—June, 1915).

(*a*) Formation of an Advisory Committee on High Explosives.

During the first two months of war the normal procedure was followed in respect to all explosives. From October, 1914, until January, 1915, a succession of administrative changes were effected to meet rapidly shifting circumstances in regard to high explosives. Conditions as to the supply of these were affected in October, 1914, by an enormous expansion in the demand for both services, by the Allies' claims to participate in the output of latent British capacity and by the simultaneous decision to substitute T.N.T. for picric acid. The

[1] 70/Gen. No./2401. [2] 70/Gen. No./3520.

increased use of high explosives entailed the resumption of filling by the trade, thus breaking down absolute control by the Chief Superintendent of Ordnance Factories. The use of a new form of bursting charge made its supply a matter beyond mere purchase by a contracts department in the open market.

Technical knowledge was required to build up an entirely new industry of an extremely intricate nature. The supply of the new explosive depended ultimately upon the production of raw materials concerning which no official knowledge existed. During the month of October, the Contracts Department looked to a single expert adviser on this question, Dr. W. R. E. Hodgkinson, Professor of Chemistry at the Ordnance College, Woolwich, whose investigations[1] had served to show the difficulties of obtaining any certain information. The Director of Army Contracts, Mr. U. F. Wintour, considered it therefore desirable to associate with Dr. Hodgkinson advisers familiar with the industrial side of the problem,[2] thus applying to this particular matter his general opinion that a contract department could not properly fulfil its duties without close contact with the conditions of supply.[3]

On 10 November, 1914, Mr. Wintour approached the Secretary to the Board of Trade, Sir Hubert Llewellyn Smith, for advice in selecting a small expert committee to consider the whole situation and to take the action necessary for safeguarding the position.[4] Invitations were accordingly issued by the Board of Trade to certain experts on 13 November to serve on an informal committee, which, under the presidency of Lord Moulton, should investigate questions relating to the supply of high explosives and their raw materials. Formal application from the War Office to the Board of Trade for assistance "in advising as to methods to be adopted in order to ensure an adequate supply of raw materials for the manufacture of high explosives" was dated 16 November.[5] On the same day, the Committee on High Explosives first met at the Board of Trade under the chairmanship of Lord Moulton, who had already been investigating the war conditions of the chemical industry in relation to dyestuffs,[6] as a member of the Board of Trade Committee on the Supply of Chemical Products. Of the other members of the committee two (Mr. Percy Ashley and the secretary, Mr. S. Whetmore) represented the Board of Trade, two (Dr. C. Carpenter and Mr. W. Macnab) were expert chemists, and one was H.M. Chief Inspector of Explosives (Major A. Cooper-Key), while the War Office was represented by the Director of Army Contracts, his assistant, Mr. P. Hanson, and by Dr. Hodgkinson.[7]

(b) DEVOLUTION OF EXECUTIVE POWER UPON THE COMMITTEE.

During the month of November the committee met seven times, discussing the respective merits of requisitioning raw material or bargaining for it, the practicability of controlling certain works for purifying T.N.T., the form of Government contracts, the use of alternative explosives, and the personnel available for inspecting

[1] 74/7/849.
[2] 74/H.E./4.
[3] HIST. REC./H/170/4.
[4] 74/H.E./4.
[5] *Ibid.*
[6] HIST. REC./R/1500/1.
[7] 74/H.E./4.

manufacture. A representative of the committee was sent to France to investigate the methods of making and filling Schneiderite. Lord Moulton visited many works in person and made a general investigation of the country's manufacturing capacity.[1] On 27 November he drew up a scheme for developing British productive power in high explosives to its greatest possible extent[2] Finally, at its seventh meeting held on 30 November, the committee resolved as follows: "having considered the questions relating to the production of raw materials and finished high explosives [the committee] is of opinion, that it is necessary for an office to be established under its supervision for the purposes of the objects for which it is constituted."[3] At this meeting the committee had been notified of the terms of its reference, which were published in a formal notice of its appointment issued by the Board of Trade on 3 December, 1914. Following the War Office letter of 16 November, this notice stated that the committee was "to consider and advise as to the steps which should be taken to ensure an adequate supply of high explosives for the British and Allied Governments, and of the materials and products necessary for their manufacture."[4]

The committee's resolution was in effect a demand for executive power. It was in agreement with conclusions at which Lord Moulton and Mr. Wintour had recently arrived[5] in view of powers taken by the War Department under sub-section 3 of the Defence of the Realm (Consolidation) Act,[6] which enabled the Admiralty or the Army Council to requisition the output of factories and thus put into effect a recent recommendation made by the Committee on High Explosives that parliamentary powers should be taken to control the whole output of toluol.[7] Lord Moulton and Mr. Wintour considered that the duties of the committee should include firstly supervision of the production of raw materials, benzol, toluol, and carbolic acid, and possibly acids and acetone, so as to ensure that plant was used to its maximum capacity and that production took place along economic lines; secondly, control over the distribution of products to the makers of the finished explosive; and thirdly, the building of new plants and the adaptation of derelict works, the committee having already recommended that steps should be taken to acquire certain plant suitable for purifying T.N.T. The duties of the committee's new "office" would thus be to "examine existing contracts, inspect works, advise on the extension or modification of plant for the production of everything from the raw material to the finished explosive, and control the movements of the various substances between the works in this country."[8]

Permanent offices for the use of the committee were established at Storey's Gate on 2 December, 1914. Its personnel was strengthened by the addition of Sir Reginald Sothern Holland, formerly Trade Commissioner in South Africa, who since the outbreak of war had

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[1] Hist. Rec./H/1520/11. [2] Hist. Rec./R/1520/8. [3] 74/H.E./40.
[4] 74/H.E./4. [5] 74/H.E./41
[6] *Parliamentary Debates* (1914) H. of C. LXVIII., 1275.
[7] Meeting of Committee on High Explosives. 20/11/14. (74/H.E./40).
[8] 74/H.E./41.

taken an active part in organising British industry with a view to capturing German trade. At the same time, Mr. Whetmore was succeeded as secretary by Mr. R. R. Enfield. Application was made by the Board of Trade to the Treasury to sanction the expenditure on headquarters staff inclusive of four inspectors. The committee thus became a permanent and authorised organisation; but the methods by which it should acquire executive power, or even whether it should have such power at all, were questions which remained undecided for some weeks.

In the meantime the Contracts Department of the War Office was taking emergency measures for increasing the supply of high explosives, which virtually constituted the War Department the sole supply authority for T.N.T., not only for the army but also for the navy and the Allies. It would shortly be necessary to control the erection and management of national plant for T.N.T. manufacture. When trade filling began, an authority for storekeeping and issuing high explosive to the Ordnance Factory and filling contractors would be needed. The novel and technical nature of T.N.T. manufacture made a system of inspection at the various stages of production essential. Although the Contracts Directorate had intervened in a time of urgency, many of these duties lay without the scope of its functions. It was particularly necessary to regularise financial procedure and to define the authority responsible for fixing the price of the controlled products. The work of the Ordnance Factories was already so congested that the Chief Superintendent of Ordnance Factories was unwilling to undertake the control of high explosive manufacture or to become responsible for storing any explosive beyond that for his own requirements. The Deputy Director of Ordnance Stores was not accustomed to organise removal of products from one contractor to another, an essential part of the scheme for making and purifying T.N.T. The position of the Committee on High Explosives was anomalous. Under the terms of reference, it possessed advisory powers only; yet circulars issued to toluol producers had established it as the sole authority for communicating decisions in respect to output, while for the committee to issue directions would be an encroachment on the powers taken by the Army Council under sub-section (3) of the Defence of the Realm Act.

Alternative suggestions were put forward at a conference on 11 December, 1914. It was first proposed that the Committee on High Explosives should be established as an executive Department of State to control the supply of high explosives for the army, navy and Allies. To this it was objected that the committee had no experience in War Department contract work or cost accounting; that it would be undertaking duties for which the navy and army were essentially responsible; that legislation would be necessary for any other Department to control output under the Defence of the Realm Act; and, finally, that parliamentary representation would be necessary if the committee were to draw on a separate vote of credit and that the provision of a suitable organisation would thereby be delayed. The alternative suggested was to establish a new branch of the

Directorate of Artillery, in order to utilise the expert knowledge of the War Office staff in inspection, storekeeping and cost accounts, to retain in the hands of the Secretary of State control over high explosive supply for the army and to avoid the delay inseparable from the establishment of a new Department. The main disadvantage foreseen was that supply would thus be undertaken by the War Department for the navy and Allies. It was unanimously agreed that the scheme for making and supplying T.N.T. should await a decision on the administrative question and that a prompt settlement was, therefore, of great urgency.

Apparently any idea of establishing a separate Department of State for the supply of high explosives was immediately abandoned. During the following week, Sir George Gibb took an active part in negotiating a definite administrative settlement. On 17 December he reported to Lord Kitchener that the problem was one of industrial organisation and that an immediate decision was necessary in order to prevent a grave failure in the supply of high explosives during the next year. In his opinion, executive power should be given to Lord Moulton, assisted by his committee, together with the necessary staff experienced in accounting, to be provided by the Finance Department. In order to overcome the difficulty of assigning to the Master-General of Ordnance responsibility for the action and expenditure of a branch in which he was unrepresented, Sir George Gibb had himself offered to undertake the general administration of a separate vote to be expended by Lord Moulton; but the financial authorities of the War Department considered this course impracticable. Sir George Gibb, therefore, recommended that authority should be given immediately to Lord Moulton to organise his staff and accommodation, receiving executive power through a representative to be appointed by the Master-General of Ordnance with full authority to give immediate approval in order to avoid delays. Pending a settlement a temporary working arrangement was made between Mr. Wintour and Sir Reginald Sothern Holland to effect prompt action in regard to the control of toluol,[1] and preliminary steps for organising T.N.T. manufacture were taken by Lord Moulton and Sir Reginald Sothern Holland on the general authority of Sir George Gibb.[2] Decision was taken on 22 December, 1914, to establish a temporary branch of the Directorate of Artillery for the supply of high explosives, chiefly for the army, but also for the navy and the Allies. At a conference in General von Donop's room it was agreed that the branch should be called A.6 and should be directed by Brig.-General W. C. Savile, D.S.O. One member of the Financial Department (Mr. F. J. Howard) was attached to the new branch for financial and accounting duties. Lord Moulton was to have executive authority from the Master-General of Ordnance in conjunction with General Savile.

Formal notice[3] of the establishment of A.6 was circulated on 1 January, 1915. Its duties were to :—

(*a*) Supervise all high explosive contracts ;

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[1] C.H.E./1508. [2] Hist. Rec./H/1520/7, Part II. [3] W.O. Office Memo. 795.

(*b*) Store and account for ingredients until they reached the stage of standard finished explosives ;

(*c*) Order materials from contractor to contractor or from store to contractor ;

(*d*) Inspect materials during manufacture ;

(*e*) Account for all expenditure chargeable against War Office funds ;

(*f*) Certify and pass bills for payment through M.G.O.F. ;

(*g*) Arrange generally for securing the adequate production of high explosives and their raw materials.

Contracts were to be passed to the War Office or the Admiralty for completion and record. Issues to the Allies were to be made on the authority of the Master-General of Ordnance, the price being settled in consultation with the Finance Department of the War Office. The new branch was definitely established as sole authority for the supply of high explosives on 7 January, 1915, when it was agreed that the Admiralty should apply to A.6 for all high explosive requirements.[1]

III. Procedure for supplying Explosives to the Allies.

Procedure in regard to Allied nations was altered almost immediately by the formation of a special Committee for the Supply of Explosives to the Allies. On 6 January, 1915, Lord Kitchener informed[2] Lord Moulton of his intention to establish a small committee which should consider how far and in what proportions the Allies could be helped from British resources for high explosives and their raw materials. In view of the political and military considerations involved the Secretary of State himself presided over the committee and made the final decision as to export. The Director of Contracts, who represented the War Office on the Commission Internationale de Ravitaillement and was responsible to the Secretary of State for meeting the requirements of the Master-General of Ordnance in respect of all munitions of war, was a member of the new committee. The other British representatives included the Master-General of Ordnance and Mr. Wyldbore Smith, director of the international commission. Lord Moulton became a member of this committee in order to establish close touch with the War Department, and his private secretary, Mr. A. Bazire, acted as secretary to the committee. Representatives of the various Allied Governments attended the meetings of the committee as occasion arose. The procedure to be followed by the Allies in applying for high explosives and their raw materials was outlined by Lord Kitchener on 30 July, 1915, and formally approved on 13 October following.[3] In January, 1917, special arrangements were made to ensure reference to the Inter-Allied Munitions Bureau in all cases where the purchase of explosives by the Allies in the United States of America was likely to cause competition.[4] Towards the end of 1917 it was agreed that in view of the increasing demands of the Admiralty for high explosives, the demands of the Allies should be strictly

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[1] 74/H.E./25. [2] 74/H.E./39. [3] HIST. REC./R/1501/1. [4] X235/11.

criticised. The allocation of supplies to them was submitted for Ministerial decision and formed one of the subjects to be considered by the newly appointed sub-committee of the War Priorities Committee, which dealt in general with the allocation of explosives and chemicals.[1]

IV. Schemes for Uniting Control over the Supply of Propulsive Explosives for the Navy and Army.

(February—May, 1915).

During the first six months of 1915, various abortive schemes were considered for uniting in Lord Moulton's hands the control over supply of naval and military propellants, as well as the responsibility for high explosives. The unexpected demands of the army for cordite had been met in part by increasing the proportion of the output from the Royal Gunpowder Factory allocated to the Land Service. After protesting in December, 1914, that "[the Admiralty] have largely maintained Waltham Abbey in time of peace and have expected to have a corresponding proportion of its production in time of war [and] cannot admit the right of the War Office to deprive the navy of the sources of explosives on which it had relied and merely to give [the Admiralty] any surplus left over after War Office needs are satisfied,"[2] the First Lord (Mr. Churchill) gave instructions on 25 January, 1915, for the establishment of an independent naval factory for cordite.[3] In accordance with a policy which had been formulated some time before,[4] the Admiralty thus obtained sole control over a national source of propellants supply which was exclusively naval. This policy was maintained throughout the war. In particular, the Admiralty negatived various proposals made by the Minister of Munitions that military requirements should be met by extending the Royal Naval Cordite Factory.[5] In order to release capacity needed by the army, the navy ceased to take cordite from the Royal Gunpowder Factory in January, 1917.[6]

The construction of the Royal Naval Cordite Factory during the spring of 1915 threatened to be too slow to meet immediate needs. On 22 February, 1915, Mr. Churchill discussed the position with Lord Moulton, who was ready, if necessary, to undertake a comprehensive scheme of production for both services.[7] Lord Moulton was already responsible for supplying certain materials common to high explosives and cordite, viz., gun-cotton and oleum. He had agreed in December, 1914, to advise Sir George Gibb on questions relating to military cordite, acetone and gun-cotton.[8] On 12 January, 1915, the Master-General of the Ordnance had definitely assigned to him the duty of supplying oleum for cordite manufacture as well as for T.N.T.[9] The

[1] D.M.R.S. 505 A1.
[2] C.P. 89166/14 (16/12/14).
[3] C.P. 101881/14.
[4] HIST. REC./H/1530/2.
[5] 95/C/289.
[6] 95/C/251.
[7] HIST. REC /R/1500/12.
[8] C.H.E. 2680.
[9] 3/GEN. NO /93.

first scheme, proposed by Lord Moulton on 22 February, was to hasten production for the navy by converting derelict works at Queen's Ferry, near Chester, into a factory for gun-cotton to be made into cordite at the Royal Naval Cordite Factory. He proposed on 23 February to give similar assistance to the army, but the Director of Artillery pointed out that orders for military propellant showed a considerable surplus at this date. It was, however, decided by Lord Kitchener that Lord Moulton should investigate the possibilities of converting some other works similar to those at Chester in order to expedite army supplies.[1] Mr. Churchill had already proposed to the Secretary of State that Lord Moulton should take over the provision of propellants of all kinds as well as high explosives, in order to have a large and co-ordinated scheme of action. Lord Kitchener agreed that Lord Moulton could greatly assist in developing new propellant factories, and that any surplus would be available to meet the great needs of the Allies.[2] This second project was transformed towards the end of March into a plan for building a nitrocellulose factory, output of which would be primarily for the Allies.[3] During April and May the supplies of propulsive explosives for both services were considered together by the Munitions of War Committee, who on 13 May, 1915, recommended that the army should release cordite capacity for the navy by utilising an alternative propellant, and that Lord Moulton should investigate the means of providing such a substitute.[4] He accordingly undertook a scheme for erecting, on behalf of the army [5] a national factory, for which a site was ultimately found at Gretna. In the meantime, the Admiralty had appointed their own adviser on cordite supplies, Sir Frederic Nathan, and expedited the schemes for naval cordite production,[6] finally deciding towards the end of May to dispense altogether with Lord Moulton's Queen's Ferry project. This was subsequently taken over for the Land Service (21 June).[7]

Thus, in June, 1915, the main result of the proposals to unite in Lord Moulton's hands control over propellant supply for both services was to place upon him responsibility for two new national factories intended solely for military purposes. The navy had strengthened its organisation and was well on the way to dispensing altogether with any output from the Royal Gunpowder Factory controlled by the War Office.

V. Formation and Development of the Explosives Supply Department.

When the Ministry of Munitions came into existence in June, 1915, the duties transferred to it from the War Office included those of the explosives supply branch (A6) and the contracts functions of the Master General of Ordnance. Thus the new Ministry became responsible for high explosives and raw materials for explosives and

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[1] 74/6/3633. [2] HIST. REC. /R/1500/12.

[3] It materialised as Curtis's and Harvey's works for supplying nitrocellulose powder to the Belgian Government, see below p. 111.

[4] HIST. REC. /R/172/1; HIST. REC. /R/172/9. [5] 74/6/3633.

[6] HIST. REC. /H/1530/2. [7] HIST. REC. /H/1122. 7/1.

also for propulsive explosives formerly purchased by the contracts authorities for the Master General of Ordnance. Control of the Royal Gunpowder Factory was taken over by the Ministry as from 23 August following.[1] The actual transference of the offices at Storey's Gate to the Ministry of Munitions took place on 23 June[2] and the branch became known as the Explosives Supply Department.

The Minister (Mr. Lloyd George) instructed Lord Moulton on 26 June to ascertain as closely as possible from the Admiralty and the War Office their estimated requirements of all classes of explosives for the various types of charges and to arrange for their production "well within the limits of Great Britain" to insure against shortage. On the same day he authorised formally the construction of the national factory for R.D.B. cordite (Gretna) and the organisation of a change over from cordite M.D. to R.D.B. by cordite makers.[3] Thus the Explosives Supply Department retained all the duties undertaken when it was established as A6, being responsible for high explosives for the army and the navy and for raw materials, certain of which were common to high explosives and propellants. In addition, it became responsible for the production of propulsive explosives for the land service, and for this purpose a separate branch had already been established, on 7 June, 1915, under Major the Honourable W. L. Bagot, who was succeeded in the following December by Sir Frederic Nathan, released from the Admiralty for the purpose. Control of the Royal Gunpowder Factory was for six months retained by the Director General of Munitions Supply under whom all the Ordnance Factories were placed upon their transfer to the Ministry. On 14 January, 1916, responsibility for the supply of propellants for the army was centred in the Propellants Branch of the Explosives Supply Department by the transfer to it of control over the Royal Gunpowder Factory.[4]

The question of adjusting arrangements in respect to propulsive explosives for the navy was raised by Sir Hubert Llewellyn Smith at a conference with the Director of Navy Contracts (Sir Frederick Black) on 7 June, 1915. It was agreed that any questions as to allocating capacity could be settled in conference.[5] From time to time throughout the war such settlements were effected by mutual agreement. A proposal made by cordite manufacturers (10 June, 1915) that the trade should take part in these conferences was rejected on the ground that the allocation of orders pertained solely to the services.[6] In order to avoid complications arising out of the manufacture of naval and military cordite in the same works, it was arranged in September, 1915, to allocate the whole output of certain firms to each service.

The adjustment of high explosive demands between the Admiralty and the War Office became a matter of importance in the autumn of 1917, when the requirements for large quantities of T.N.T. to be used by the navy in "destructors," threatened to restrict drastically the

[1] 1/Gen. No./1559 Cl.
[2] 74/B/275.
[3] Enclo. to Gretna 2891, No. 1, ff. 51-52.
[4] HIST. REC./R/263.032/34.
[5] C.P. 88733/15.
[6] Minutes of Proceedings at a Conference on R.D.B. between the manufacturers and the Ordnance Board.

quantities of this explosive which would be available for other purposes. Some definite correlation of the programme for the naval, land and air service became essential. The question of the demand for destructors was considered by the War Priorities Committee on 31 October, 1917.[1] During the first week of November it was decided[2] to form a Sub-Committee of the War Priorities Committee to deal with the allocation and use of chemicals and explosives; the secretary to the committee was Mr. D. G. Duff, then personal assistant to the Controller of the Explosives Supply Department.[3] The committee continued to deal with these questions throughout the remaining months of the war.

VI. The Organisation of the Explosives Supply Department.

In January, 1915, the Explosives Branch of the War Office was staffed with officials dealing with the control and supply of raw materials, the erection of new plant, and the general organisation of high explosive production and storage throughout the country. This staff increased with great rapidity as the work of the branch expanded. Upon the formation of the Explosives Supply Department in June, 1915, Lord Moulton became Director General with Sir R. Sothern Holland as his deputy and Brigadier-General Savile as military adviser. The administrative organisation at headquarters remained unaltered throughout the war save for certain changes in personnel. Thus Mr. Keith Price, who had at first taken the responsibility for the supply and control of coal tar products, succeeded Sir R. Sothern Holland as Deputy Director General of Explosives Supply[4] in March, 1916, when the latter became responsible for inspection of all munitions. Mr. Price was assisted by Lieutenant A. Corbett, who had joined the staff in December, 1914, as legal adviser to Lord Moulton. Upon the formation of the Munitions Council in August, 1917, Sir Keith Price became council member directly responsible to the Minister for Group X, which included the Explosives Supply Department, the Mineral Oil Production Department and the authority responsible for Chemical Warfare Supplies. Simultaneously, Lord Moulton's immediate deputy, Major A. Corbett, received rank as Controller of the department.

The scope of the department's main duties remained unaltered between June, 1915, and the year 1918, except that the control of certain materials developed naturally out of its other functions. Thus the control of the soap and candle industry was undertaken to secure adequate supplies of glycerine until the Ministry of Food was established; and the control of the fertiliser trade arose similarly out of the department's interest in the supply of acids. In the spring of 1918, the Explosives Supply Department became responsible for chemical warfare supplies, and an arrangement was made whereby the Controller of Mineral Oil Production reported to the Minister through Lord Moulton.

[1] 74/Admiralty/87.
[2] D.M.R.S. 505 A1.
[3] For the Minutes of the Committee see X237/23.
[4] X235/125.

(a) Duties of the Department.[1]

The duties of the Explosives Supply Department began with materials essential to manufacture, whether in the raw or intermediate stages. Its function towards these varied, from simple purchase in the open market, through various degrees of control over the whole of the country's output or import of essential ingredients up to State manufacture. The absorption by the department of the whole output of certain materials, such as toluol, or decisions taken to become responsible for the supply of other materials to contractors entailed fresh duties, such as the allocation of the material concerned among various industries. In this way, also, the department in some instances developed new duties in regard to substitutes, the use of which it encouraged in order to free essential materials for explosive manufacture. Thus the Acid Supply Section of the department stimulated the use of nitre-cake in place of sulphuric acid in many and various industries. These activities are described elsewhere.[2]

Manufacture of explosives took place stage by stage, often in widely distant localities. The department was responsible for sending the finished product to store or to the filling factories. In order to meet these conditions transport arrangements were controlled generally by a separate Railway Section. The control of distribution was the concern of various sections. Thus the "Contracts" Section, concerned chiefly with the supply of finished high explosives, was responsible for their distribution; the Acids Section for the consignment of acids to contractors and national factories, and for the transport of nitre-cake and other materials.

The department negotiated and administered all contracts for complete explosives. In this respect, its organisation was distinct from that of the main body of the Ministry. The so-called "Contracts" Section of the department was, in fact, a supply section responsible not only for placing but also for administering contracts. Every supply officer of the department was a contracts officer responsible for the terms of agreement when once he had satisfied the Finance Branch of the department that they were financially sound.[3] He negotiated contracts and submitted them to the Finance Branch for approval, after which the contract was formally drafted by the legal advisers attached respectively to the department as a whole and to the Propellants Section.

This arrangement dated from the initiation of the Explosives Branch of the War Office during the winter of 1914–15.[4] It was facilitated by the fact that a certain proportion of the administrative officials who then joined the branch possessed considerable legal experience and were capable of dealing with the many intricate legal questions arising out of the technical nature of the supply.

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[1] The functions of the various sections are based on the Report to the Staff Investigation Committee (Hist. Rec./R/263.5/14), showing the position in April, 1918.

[2] Vol. VII., Pt. IV.

[3] Memo. by Major Corbett, January, 1918.

[4] Minute on Procedure, 12 January, 1915 (Hist. Rec./R/263.5/11).

A very large proportion of the department's work related to the initiation and control of national factories. From January, 1915, until June, 1916, this work was distributed among various sections of the department. Agreements in regard to sites, agencies and other similar matters were negotiated by the legal officers within the department. With certain exceptions, the lay-out and equipment of the various installations were the work of the Construction of Factories Branch under a technical director, Mr. K. B. Quinan, General Manager of the Cape Explosives Company, whose services were lent by the De Beers Consolidated Mines Company in December, 1914, primarily for the construction of the first national T.N.T. factory at Oldbury.[1] Technical control over the erection of the high explosive factories during this period was exercised by Mr. Quinan's section; the general administration by the "Contracts" Section. With the rapid increase in the numbers of government factories, it became necessary in June, 1916, to establish a Factories Branch concerned solely with their administration, the appointment of staff and all constructional work.[2] The new branch was under the direction of Mr. Quinan. The investigation of costs and efficiencies within the national factories became a very important part of its work. It had its own subsection for buying and inspecting plant and material; a system which developed out of the appointment of a member of the firm of Sir J. Wolfe-Barry to control purchase of material for the construction of the factories at Queen's Ferry and Gretna. The general running stores of the department, including clothing, chemical apparatus and certain engineering stores, were provided by a central stores section established in December, 1915, to secure the advantages of central buying.[3] A section was similarly established in November, 1917, for the central purchasing of coal for all National Explosives Factories.[4] The general importance of an enormous water supply led to the appointment of a separate adviser on this question, Mr. Hawksley, first appointed in July, 1915, to lay out the works needed to provide Gretna with its requirements of 6,000,000, gallons a day.[5]

From November, 1915, onwards a separate section dealt with all labour questions at explosives works under the department or its contractors, acting in consultation with, but independently of, the Wages Section of the Ministry and the Building Labour Committee.[6] The department also had its own housing branch concerned with designing, estimating cost and supervising the erection of houses in connexion with explosives factories.

The national factories controlled by the Factories Branch excluded the agency factory for T.N.T. at Oldbury and two T.N.T. purification works, viz., Rainham and Gadbrook, which remained under the administration of the Contracts Section. The Royal Gunpowder Factory was placed under the control of the Propellants Branch in January, 1916, and this section administered the newly erected propellant factories; but the national factories at Gretna,

[1] 74/H.E./22. [2] Major Corbett Unregistered Memo. 13/4/16; 74/H.E./1070.
[3] 74/P/169. [4] 74/Estab./168. [5] 95/2/172. [6] 95/1/2; 74/F/12

Queen's Ferry and Pembrey remained under the control of the Factories Branch, whose director, Mr. Quinan, had been responsible for the lay-out and erection of the first two of these.

The importance of testing and inspecting high explosives in the various stages of manufacture was one of the main grounds for establishing a separate organisation for high explosive supply in December, 1914. Among the officials appointed in the winter of 1914–15 were chemical inspectors to visit high explosive works and several inspectors of distilling plants to examine and advise on the methods used in distilling toluene.[1] By means of a staff of visiting chemists reporting (from March, 1915, onwards) to the Chief Chemist at headquarters (Dr. R. C. Farmer), intimate knowledge of the progress made by contractors was ensured. The effective supervision thus established succeeded in raising the quality of the finished high explosives up to the high standards required by British specifications.[2] The actual sentencing of the completed explosive rested originally with the Royal Laboratory, and remained thus so long as it was the only establishment engaged in filling shells, and the explosive was regarded for this purpose as a raw material. Tests were made for the Royal Laboratory by Chemist I.D. In June, 1915, local inspection staffs were organised in connexion with the chief universities throughout the country, whither samples were taken for testing.[3] Responsibility for this scheme was handed over to the Chief Inspector, Woolwich, in the following August[4] and a distinct directorate for the inspection of high explosives was then established.[5] The staff of inspectors at the Explosives Supply Department worked in close touch with the Woolwich Inspectors who interchanged information, enabling the Chief Chemist to supervise methods of production in the light of final inspection results.[6] A separate division of the Inspection Department, Woolwich, existed for testing and sentencing propulsive explosives at the outbreak of war. The supply department was thus somewhat less concerned in the inspection of propulsive explosives than that of high explosives. The Propellants Branch established a close technical control over operations in both national and trade propellant factories whether working for the navy or the army.

The Explosives Supply Department had its own storage section, which was responsible for providing and administering magazines for finished explosives and receiving all propellants and gunpowder, and the reserve stock of high explosive, the current supply of which was delivered straight to the filling factory. It was responsible also for issue from magazine to filling factories or to Allied purchasers. The organisation of storage facilities for high explosives formed an important part of the work of "A 6" during the first six months of 1915, and was then directly controlled by General Savile. When responsibility for propulsive explosives was taken over from the War Office in the summer of 1915, a special organisation was needed for storing the large quantities of nitrocellulose powder which were

[1] Sir R. Sothern Holland to Mr. Wintour, 8/12/14; 74/H.E./70.
[2] Hist. Rec./H/1500/2. [3] 74/H.E./340. [4] 74/H.E./410.
[5] Hist. Rec./H/900/9. [6] Hist. Rec./H/1500/2.

about to arrive from America. The storage of propulsive explosives, considered as components of ammunition, was a function of the Ministry of Munitions.[1] By November, 1915, the supplies of high and propulsive explosives in store were steadily increasing and the Storage Section of the Explosives Supply Department was established at the end of that month under Colonel H. W. Kempster.[2]

An inspector of magazines (Colonel A. W. Bridgman) had already been appointed to control safety conditions during storage. He continued to act in this capacity until May, 1916, by which date Home Office inspectors were visiting these magazines and the Storage Section was fully organised for supervising methods of storage.[3] Responsibility for safety conditions, both in the magazines and in factories, was transferred to a Safety of Factories Branch of the Explosives Supply Department in October, 1916.[4] The development of the duties of this branch is described below.[5] Questions relating to the policing and guarding of explosives factories and magazines were the direct concern of General Savile as military adviser to the department.

A separate branch of the Finance Department was attached to the Explosives Supply Department and housed near it. This branch (known first as M.F. 3 and later as X.F.C.) was formed under Mr. P. G. Henriques in July, 1915, to supervise the financial side of all contracts and expenditure on national factories, and to take charge of cost accounting both for finished explosives and for their raw materials. It was controlled by the Director of Munitions Finance. One section of it (known as M.F. 3A.) under Mr. F. J. Howard, originated in the staff detached from the Finance Department of the War Office in December, 1914.

(*b*) MAIN FEATURES OF THE ORGANISATION.

The organisation of the Explosives Supply Department had two main characteristics which differentiated it from the administrative system throughout the Ministry. In both instances, the distinction was due to the circumstances of the department's development.

Firstly, the department was self-contained in respect of its common services. It has been seen that it had its own organisations for dealing with labour, housing and transport questions, which were allied with the corresponding bodies of the Ministry rather by mutual goodwill in serving a common purpose than by any formal procedure. This state of affairs was due to the advanced stage which the organisation of A6 had already reached when it was absorbed by the newly created Ministry of Munitions. The existence of separate organisations for controlling raw materials and storage was based on a condition in itself more lasting, viz., the essential differences in circumstances attending the production and custody of high explosives and those of other munitions.

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[1] 74/H.E./565.
[2] 74/K/61.
[3] 74/B/551.
[4] 74/Estab./43, E.S.D. Departmental Minute 31.
[5] Chapter X.

Secondly, the internal organisation of the department did not allow of any very clearly defined limits between the duties of the various sections. Several important national factories were controlled by sections other than the Factories Branch, and that branch itself administered contracts as well as national factories in the case of chemical supplies. The control of raw materials was not restricted to the "Raw Materials" Section, which dealt only with certain products for high explosive manufacture, viz., toluol, benzol and carbolic acid, and was not entirely responsible for all of these, since the production of toluol from gasworks and tar distillers was administered by the Gas Works Products Section. The Propellants Branch administered the production of several very important materials, including some which were utilised by other departments, and by the trade of the country generally, as for instance, glycerine and alcohol. It was held by the department that these apparent anomalies existed rather in the nomenclature of the sections than in any real lack of logical organisation. They were due to the gradual development of the department and were based on the high degree of technical knowledge needed in addition to administrative ability. For this reason, a close personal contact was required between the supply officers and the particular factories and firms with which they had to deal.[1]

The staff gathered together during the winter of 1914-15, chiefly through the activities of Sir R. Sothern Holland, included experts from all parts of the Empire, a large proportion being drawn from the South African mining industry. While the various sections of the department had members with special technical knowledge, research work was the particular concern of the Chief Chemist, who was appointed in March, 1915.

The department's work began with the control of raw materials and ended with the issue to filling factories or to the Allies. Nominally, therefore, it included no duties in relation either to programme making or to design in the sense of approval. In point of fact, the department's activities influenced very strongly both the quantity and quality of the explosives produced, since from the very beginning these depended respectively on the amount of raw material available as estimated by the department, and on detailed investigation which alone could enable novel explosives to be produced and used with safety and efficiency. The calculation of the country's toluene and phenol output, as a means of estimating the ultimate production of high explosives was the first work of the new department in December, 1914. Towards the end of 1916, a "Consulting Chief Inspector" (Professor J. G. Lawn) was appointed to study, balance and correlate supply and demand. At the reorganisation of the department consequent upon the establishment of "Explosives" group of the Munitions Council, he became director of a statistical section and acted as a member of the Statistical Conference of the Ministry.[2] He also served on the Explosives and Chemicals

[1] Hist. Rec./R/263.21/7. [2] 74/L/157.

Sub-Committee of the War Priorities Committee. The ultimate effect of the investigations under the Explosives Supply Department and at the Research Department, Woolwich, in changing the nature of high explosive shell has already been considered in detail. Very similar work was carried out by the authorities responsible for the supply of propulsive explosives. Research Department, Woolwich, remained throughout the war the technical adviser to the design authorities of the Admiralty, War Office or Ministry of Munitions who were responsible for final approval of any change. Information as to practical experience obtained by the Explosives Supply Department in regard to high explosives was secured to the Ordnance Committee by the service of the Chief Chemist and other officers of the department as members of the committee. Close personal touch between the Chief Chemist and research and inspection authorities at Woolwich Arsenal, from whose staff he had been drawn, worked to the same end.[1]

[1] HIST. REC./R/1500/14.

CHAPTER III.

HIGH EXPLOSIVES: THE INITIATION OF CAPACITY.

I. Purchase in the Open Market.

(a) Position at the Outbreak of War.

When war was declared the navy and the army were relying upon picric acid as the bursting-charge for all natures of high explosive shells.[1] Since 1908, the reserve of this explosive held by the Ordnance Factory on behalf of the navy had been fixed at 150,000 lbs. In March, 1908, it had been decided that no special stock need be held for the comparatively small requirements of the army. Small orders had been placed to encourage the trade, and in 1907 it had been calculated that, in the event of need, 150,000 lbs. could be obtained within a month of the placing of orders.[2] The position had been reviewed biennially since 1908; but apparently no change had been made in the policy outlined above. The arrangement covered the requirements for the Royal Laboratory only, and made no allowance for contractors' supplies, should filling be resumed by the trade, as it had been during the South African War. Neither does there appear to have been any revision to meet the gradual diminution of the country's picric acid capacity on the one hand, and on the other, the development of naval armaments, the increased proportions of high explosive shell, or the adoption of picric acid in armour-piercing shell, although suggestions to this effect had been made by the Superintendent of Ordnance Stores (Captain B. H. Chevallier), and the Chief Superintendent of Ordnance Factories in 1912.[3]

Shortly before the outbreak of war, the filling of large naval shells had been suspended on account of certain prematures. These had been ascribed to the use of "Waltham Abbey" acid, *i.e.*, picric acid recovered at the Royal Gunpowder Factory from the sodium picrate obtained by emptying lyddite shell. Filling with trade picric acid was resumed on 31 July, 1914. On the previous day, the Chief Superintendent of Ordnance Factories asked that orders, amounting in all to 504,000 lbs. of trade picric acid, should be immediately placed for delivery not later than the end of October.

(b) The First Orders for Picric Acid.[4]

Within a fortnight of this first demand, it was apparent that the trade was unable to fulfil the part which had been assigned to it. The first month of war could not suffice for the re-establishment of plant which had been closed down for years, entirely dismantled or converted to other uses. The raw material for increased output was not readily available. Five firms only out of the seven upon whom dependence had been placed in 1912 were able to tender for immediate supplies.

[1] See above, p. 4.
[2] 70/Gen. No./2407.
[3] 70/Gen. No./3520.
[4] Based on Contracts/A/2598.

Proposals to extend capacity for future use were at first discouraged or deferred in favour of the more urgent needs of immediate supply. The orders for the 504,000 lbs. were distributed among the five firms who promised first deliveries within a fortnight. On one instance only was a contract terminable later than October. The Chief Superintendent of Ordnance Factories pressed for the supply of any quantities available within the next few weeks; but all the efforts of the Contracts Department secured only slightly increased deliveries from two contractors. Actual deliveries of picric acid during the first three months of the war averaged 60,000 lbs. weekly.[1] The initial orders for 504,000 lbs. were sufficient to fill naval shells for three weeks only. Neither service favoured the resumption of filling with recovered picric acid, of which 67,000 lbs. could have been produced from the existing stocks of sodium picrate.

By 11 August, 1914, the Chief Superintendent of Ordnance Factories had realised the discrepancy between the trade capacity and the requirements of the two services. Accordingly he pressed not only for immediate purchases but also for the extension of "every encouragement to any likely contractor to conserve and develop any facilities he may possess for the production of picric acid as we shall almost certainly be requiring further quantities even although they cannot be supplied until after October or November."[2] At the same time he proposed that certain explosive makers, notably Messrs. Kynoch, should be approached with a view to obtaining T.N.T. Eventually, the only cordite firm which took up the new industry was Nobel's, who built and managed a T.N.T. factory at Pembrey, and had already had experience in its manufacture at Ardeer.

Towards the end of August orders were placed with existing contractors for a total of 320,000 lbs. of picric acid for delivery in September and October; but the only contract for later delivery was an order for 260,000 lbs. to be completed by the end of January, 1916.[3] During September no further orders were placed for this explosive and the efforts of the contract department were concentrated upon replacing it with T.N.T., certain of the best picric acid makers being informed that the War Department would in all probability purchase no more lyddite.[4]

(c) Attempts to Replace Picric Acid with T.N.T.

The adoption of T.N.T. as a bursting charge had been under consideration for some years; during the last three weeks of August, 1914, it became an actual fact.[5] The use of T.N.T. in filling large naval shell began on 29 August. During September it was used in charging trial issues of 18-pdr. for France. From mid-August it was the accepted filling for naval mines. Until 14 August, small orders only had been placed with two firms (Leitch & Co., and Nobel's) for the finely powdered T.N.T. used in exploder bags. On that day, the Ordnance

[1] Hist. Rec./R/1500/16.
[2] Contracts/A/2598 (11/8/14).
[3] *List of Explosives Ordered*, 6/11/14.
[4] Contracts/A/2814.
[5] See above, Chap. I.

Factories made a demand for 300,000 lbs., one-third of which was immediately purchased from stock held by the Explosives Loading Company towards its filling orders for other Governments. Orders for the remaining 200,000 lbs. were equally divided between Nobel's and Leitch & Co. These two firms, with the Clayton Aniline Company, were then the only existing makers of T.N.T. in the kingdom. The Clayton Aniline Company were dye-makers controlled by the Society of Chemical Industries, Basle, and manufacturing for export a crude product which did not meet the specification originally laid down for T.N.T. exploder bags and temporarily adopted as the standard for T.N.T. bursting charges.[1] Continuation orders were placed with Nobel's and Leitch & Co. to meet a further demand for 162,000 lbs. on 2 September. The attempts made during that month to induce picric acid makers to turn over to T.N.T. were unsuccessful, most of the firms approached being unwilling to enter upon an entirely new business with which they had no acquaintance. Towards the end of the month, the use of T.N.T. in smaller natures of shell for land service was formally approved. A demand for 500,000 lbs. arose immediately. Negotiations were set on foot for obtaining practically the whole amount from a single firm of coal-tar distillers (Brotherton & Co.), who had already undertaken a project for picric acid manufacture; but the date of delivery was quite indefinite and depended upon their success in installing the picric acid plant. The entire dependence upon so uncertain a source for so large a quantity marks the breakdown of the attempt to substitute T.N.T. for picric acid by normal methods of purchase in the open market. The average weekly deliveries of this explosive during August, September and October were 26,000 lbs. only.[2]

(*d*) Renewed Orders for Picric Acid.

The demand for high explosive was increased by an extension of the naval mine-laying programme announced on 4 October, 1914. The number of mines to be filled at Woolwich was then raised from 70 to 600 weekly. A sub-contract for filling 7,500 mines with T.N.T. was also undertaken for Messrs. Vickers by the Explosives Loading Company, who obtained a certain quantity of granular T.N.T. from Nobel's factory at Ardeer.[3] Other explosive-filled stores such as aircraft bombs and sweeping charges were rapidly developing. The Admiralty alone expected to use 3,400,000 lbs. of T.N.T. by the following July.[4] The probability of an immense increase in the proportion of high explosive shell to be used in the field raised the future needs of the land service from comparative insignificance to extreme importance. With the first frosts, the engineers began to ask for supplies of T.N.T. or some substitute, as a means of breaking up the hard ground.[5] As the year wore on, the Allies, French, Russian and Belgian, became importunate in their requests for British assistance in supplying their forces with high explosives, particularly T.N.T.[6]

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[1] 74/7/849; X235/28.

[2] Hist. Rec./R/1500/16.

[3] Contracts/A/2814; *Ordnance Board Minutes*, 11586, 11953.

[4] Contracts/A/2814.

[5] General Fowke to Colonel Jackson, 24/11/14.

[6] 74/H.E./4.

It was therefore decided to continue the purchase of picric acid, at least, till enough T.N.T. should be available. The Chief Superintendent of Ordnance Factories considered that 3,000,000 lbs. of picric acid could be consumed during the last ten weeks of the year, even if the supplies of T.N.T. improved. Tenders for 500,000 lbs. of picric acid were issued on 15 October, and by the end of the month orders had been placed with five firms for over 2,000,000 lbs., the bulk of which was to be delivered by July, 1915. Two of the five firms from whom this additional amount was obtained were new contractors. The one (R. Graesser, Ltd.,) had plant which had fallen out of repair before 1912[1]; the other, a firm of tar-distillers (Brotherton & Co.), had previously failed to obtain a Home Office licence for a picric acid factory in Leeds, owing to local opposition.[2]

Two considerable offers were refused since they involved in the one case a high price to cover rises in the cost of the raw material (phenol), in the other a scale of prices dependent thereon.[3] In mid-November the conversion of the stock of sodium picrate was begun, but its use was sanctioned only for filling aerial bombs and naval mines.[4]

(*e*) UNCERTAINTY AS TO SUPPLIES OF RAW MATERIALS.

An exact knowledge of the quantities of coal tar products available as material for the manufacture of either picric acid or T.N.T. was essential to any organised expansion in the output of these explosives. Official information on this point was scanty. Contractors alleged that speculators were holding up supplies, and that the orders prohibiting export of nitro-derivatives of tar were being contravened. The needs of the dye-industry were in direct competition with those of explosive makers. Tenders for toluol issued to 100 firms produced only 12 offers for insignificant amounts. The benzol distillers had not the necessary plant for recovering toluol, nor did the administrative machinery exist to force them to do so. The expansion in T.N.T. manufacture by methods then known would involve large quantities of oleum, only obtainable from abroad. The circumstances of the supply of these materials are considered in detail elsewhere.[5] The need for technical knowledge in dealing with the industrial side of this problem led to the formation of the Committee on High Explosives[6] under Lord Moulton, which investigated the whole position in respect to the supply of high explosives and their materials throughout the month of November.

Emergency Methods (November—December, 1914).

(*a*) POSITION, NOVEMBER, 1914.

The position was reviewed as a whole by the Contracts Department on 5 November, 1914.[7] It was estimated that the total requirement from November to July would be at a fixed rate of 304 tons of high explosive monthly, *i.e.*, that a total of 2,736 would be needed by

1 70/Gen. No./3520.
2 74/H.E./72.
3 Contracts/A/2814.
4 *Ordnance Board Minutes*, 11340, 11953, 12052.
5 Vol. VII., Pt. IV.
6 See above, p. 22.
7 Contracts/A/2814.

the end of July, 1915. Of this, 197 tons would be used by the Chief Superintendent of Ordnance Factories each month, 107 tons monthly for the new filling requirements of the Admiralty, exclusive of the 67 tons of T.N.T. which the Explosives Loading Company was to receive from Nobel's for mine-filling, no allowance being made for this contract in the review.

Against these requirements, the promised deliveries of picric acid and T.N.T. looked very well on paper. The aggregate by the end of July would be 4,857 tons. In the month of November alone did the requirement exceed the supply and stock enough existed at the Ordnance Factory to cover this deficit, even without the use of recovered picric acid. Arrangements had been made to decrease the supplies of picric acid as deliveries of T.N.T. came forward; but picric acid had been over-ordered to cover practically the whole requirement.

On the other hand, the actual position was far more grave. It was known that little reliance could be placed upon the promised deliveries, particularly of T.N.T. The development of the capacity for this explosive was very largely dependent upon the uncertain factor of the raw material supply. Moreover, the requirement had been calculated on an extremely limited basis, viz., the maintenance of the Ordnance Factory filling programme at an even rate equal to that of November, 1914. This in itself made no allowance for the increased proportion of high explosive shell for the land service, then under discussion. No provision was made for supplies to the Allies. Lord Moulton at the first meeting of the Committee on High Explosives on 16 November, set the monthly requirement at 1,400 tons, *i.e.*, between four and five times as high as the demand of 5 November and between two and three times the amount of the deliveries promised.

(*b*) FURTHER PURCHASES OF PICRIC ACID.

During November and December the Contracts Department and the Committee put in hand extraordinary measures with a view to meeting this situation. In November, contracts covering in all 2,346,800 lbs. were placed with the established British makers at advanced prices, and enhanced rates were given for early deliveries from one or two reliable firms.[1] Towards the end of the year a purchase was made of 220,000 lbs. of picric acid through a broker. An order was placed on 28 December for 1,000,000 lbs. of American picric acid, deliveries of which were to begin before the end of the year, to continue till March, 1915, and recommence in the following June. The price paid on this contract was 5s. 9d. per lb., f.o.r., Syracuse, or nearly triple the rate for the explosive of British manufacture, which ranged between 1s. 6d. and 2s. per lb. In addition an advance was made to the American firm of £50,000 which should be repayable at the rate of 1s. 3d. on every pound undelivered by the end of 1915.[2]

[1] 74/B/30; 74/R/4. [2] 74/B/50.

(c) ACTION TO SECURE RAW MATERIAL SUPPLIES.

The measures taken to develop T.N.T. production were more remarkable, since they departed in many important respects from the normal supply procedure under the War Department. In the first place, efforts were directed to securing an adequate supply of raw materials not only for the use of the Department but also for its contractors. It was mainly for this purpose that the Committee on High Explosives was formed in mid-November. Prior to that date, investigations as to the position of the coal-tar industry had been carried out by Dr. Hodgkinson of the Royal Ordnance College, acting as technical adviser to the Contracts Department. At the end of November, the powers which were taken at the committee's recommendation under the Defence of the Realm Act enabled Lord Moulton and his staff to control the whole of the country's output of coal-tar products. Active measures followed during December to ensure that the productive capacity of the country in this respect should be fully organised for the supply of the essential raw materials for explosives. Encouragement was given to at least one contractor to instal plant for nitric acid for distribution to the makers of T.N.T. Reserves of oleum were purchased in November from America; and projects for establishing a stock of sodium nitrate were set on foot.[1]

(d) ORGANISATION OF T.N.T. MANUFACTURE.

The main problem in initiating the capacity for the manufacture of T.N.T. was the general lack of knowledge concerning methods of production. Moreover, the need for economising the available materials emphasized the importance of sound technical methods. The investigations of the Research Department into efficient and economical processes had begun in October. Output from the semi-industrial plant installed by the department and the training of chemists and operatives began in the following January.

The emergency measures taken by the Contracts Department to encourage manufacture took the form of large advances of capital to contractors who were unwilling to bear the cost of plant which they considered of no post-war value.[2] Among the most notable of these agreements was a contract with a chemical engineer to convert derelict works at Hackney Wick[3] into a T.N.T. factory. The cost of purchase, construction and equipment was advanced by the State. The contractor undertook to make the explosive for three years, at the end of which the factory and plant should be his property. After an initial period of control by the department's representatives, the contractor was to produce T.N.T. at a fixed rate and price, the main materials being provided free by the department. The capital was only repayable in the event of the contractor's default. Similarly, capital advances were made to another chemical manufacturer as an inducement to undertake T.N.T. production.[4]

[1] See Vol. VII., Pt. IV.
[2] HIST. REC./R/1500/2.
[3] Vol. VIII., Pt. II.
[4] 74/H/9.

Again, firms were unwilling to take the risk of fluctuations in the cost of materials, and to overcome this difficulty the contract price in four instances was based on a sliding scale according to the cost of toluol. The T.N.T. agreement reached with Brotherton & Co. allowed also for variation in price according to the date of delivery.

By the end of the year, such financial inducements had persuaded four additional firms to undertake the production of T.N.T.; but the fulfilment of contract promises was quite undependable by reason of the novelty of the industry. Negotiations were begun with each of the three established makers of the explosive to expand their output. Nobel's agreed to erect and manage at Pembrey a T.N.T. factory, of which the State should bear seven-tenths of the cost. Leitch & Co. contracted to supply 600,000, lbs., delivery beginning from the second week in November; but the firm refused to take the risk in respect to the cost of labour and materials, or post-war value of plant, grounding its claims in part upon the expansion of the industry at the department's instigation.[1]

The utilisation of the crude product from the works of the Clayton Aniline Company as well as a part of the output of Leitch & Co. was dependent upon the capacity needed for working it up to the standard specification for pure T.N.T.[2] A very large stock (1,792,000 lbs.) of crude T.N.T. held by the Clayton Aniline Company was brought to light by Dr. Hodgkinson's investigations during October and purchased on 7 November.[3] Later in the month, Lord Moulton arranged that the firm should deliver a further supply of 3,360,000 lbs. of "pellite" or crude T.N.T. to any works capable of re-crystallising it.[4] The company itself then lacked plant for this purpose.[5] The method of crystallisation by means of alcohol, which was the only system of purification used at the time, was both difficult and dangerous. Scarcely any chemical plant suitable for the purpose then existed in the country. Plant which could be readily adapted existed at Rainham, co. Essex, where a factory had recently been established for obtaining from potatoes the butyl alcohol required for the manufacture of synthetic rubber. This factory was seized by the War Department under the Defence of the Realm (Consolidation) Act on 28 November, 1914, the day after the Act became law. It was transferred to agents who undertook to convert the plant and use it for the purification of crude T.N.T. at a fixed rate based on the amount of the crude product treated. There was considerable delay in bringing the output of the factory up to estimate. Accordingly, during the winter, the purification unit attached to the semi-industrial plant at the Research Department, Woolwich, was hurried forward with a view to converting the crude T.N.T. available into a form fit for military use.

The existing capacity of the country was practically exhausted by these measures. Home supplies were therefore supplemented by purchases of T.N.T. from abroad. In November, an agreement was

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[1] C.H.E./1919; Contracts/T/4643.
[2] *Ordnance Board Minutes* 11618.
[3] Contracts/T/4648.
[4] 74/C/27.
[5] 74/H.E./40.

negotiated with an Italian firm for 67,200 lbs. of T.N.T. in exchange for an equivalent amount of toluol, the British stocks of which then exceeded the capacity for nitration. The arrangement was, however, cancelled after about one-third of the deliveries had been made, while a later arrangement for 112,000 lbs. of the explosive did not materialize at all.[1] The United States of America were the only other source from which the importation of T.N.T. was arranged before the end of the year. An offer of 1,570,000 lbs. for delivery between 31 January and December, 1915, was made by the du Pont de Nemours Company, through Nobel's, and accepted on 22 December.[2] A second offer from du Pont of T.N.T. to be delivered during the last two months of 1915 was made through Messrs. Vickers and accepted under protest from the Committee on High Explosives, who anticipated that by the end of 1915 home manufacture would have been sufficiently developed to meet all requirements.[3] Deliveries between June and December, 1915, of 600,000 lbs. of high grade T.N.T. from Semet, Solvay & Co. were, however, accepted at the end of December in order to provide a margin of safety.[4] These American supplies were only obtained at greatly inflated prices, the effective prices being not less than a dollar against the British rate, which was usually 1s. 6d., and in no case exceeded 2s. the pound. American firms in some instances insisted upon payment of 50 per cent. of the total contract payment in advance.[5] Moreover, the American product fell below the standard of purity required by the British specification, and accordingly it became necessary to treat the explosive at the Rainham works before it was fit for use.

(e) POSITION AT THE END OF 1914.

By the end of the year, considerable advances had been made both in preparing to meet the requirements of 1915, and in bridging the critical months of the winter. During December and January, the Ordnance Factory was kept supplied with just enough high explosive to meet each week's filling programme.[6] Investigations following upon the decision to acquire the whole toluol output of the country had set the department in a position to judge how far this material would limit output; but the knowledge of manufacturing conditions remained so uncertain that it was not clear whether the ratio of toluene to the T.N.T. produced from it would be as two to three or as one to one.[7] The efficiency of the process which the Research Department was working out had not yet been fully established. The immediate needs of the 1915 campaign were to be met by large overseas purchases of picric acid and T.N.T. at inflated prices and by treatment of stocks of commercial T.N.T.

The exact amount of high explosive which would be needed was still quite uncertain. The demands of the army rested upon the contentious question of the proportion of shrapnel and high explosive shell. The specific demands for the navy and the army had been slightly increased during December.[8]

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1 *Statement of Contracts*, May, 1915.
2 74/D/7.
3 Contracts/T/4931.
4 74/S/45.
5 74/D/7.
6 74/H.E.T./21.
7 74/H.E.T./15.
8 74/H.E./46.

Action of the highest importance had been taken in the establishment of the Committee on High Explosives with executive authority to organise supply. Lord Moulton was preparing to exercise his powers to the full. Schemes were in hand for producing raw materials by synthesis when the natural product was unobtainable, for organising an adequate supply of certain materials to contractors and establishing a national reserve of others, and for guiding and controlling manufacture with a view to speed, economy and efficiency. In addition to these plans, a project for constructing national works for the manufacture of T.N.T. on a large scale was only awaiting the arrival of an expert technical adviser, Mr. K. B. Quinan, of the Cape Explosives Company, who had been summoned from South Africa for this purpose. The whole intent of these preparations was to develop British production in every practicable way and to organise to its utmost limit the country's capacity for chemical manufacture. In adopting this definite policy, Lord Moulton maintained that the huge expenditure of high explosives by the enemy made these measures the only safe line of action, since it was impracticable to base any specific requirement upon the experience of previous wars. Any margin of capacity could be fully utilised in meeting the justifiable expectations of the Allies. Accordingly, upon receiving executive power in December, 1914, he developed to the full these considered plans, which began to materialize with the turn of the year.

III. The Organisation of Supply.

(January—May, 1915.)

The Explosives Supply Branch of the War Department (A. 6) received full and formal executive authority on 1 January, 1915.[1] The organisation of the country's capacity for producing high explosives to its utmost limit began immediately along the lines already laid down by Lord Moulton.

(a) INCEPTION OF STATE MANUFACTURE.

The most striking measure taken was the establishment of a State factory for the production of T.N.T. At the time of the installation of the semi-industrial plant by the Research Department at Woolwich, the Director of Artillery, the Director of Army Contracts, and the Superintendent of the Research Department had been severally of the opinion that some measure of State manufacture would be needed to supply T.N.T. in adequate quantities.[2] By mid-December, Lord Moulton had concluded that the limit of the trade capacity of the country for nitrating the toluol available had been reached. Accordingly he proposed to lay down extensive Government works for this process. A step had already been taken in the same direction when the Rainham works were seized under the Defence of the Realm Act as a State factory for the purification of commercial T.N.T. Plans for the larger venture were already in hand. A technical expert, Mr. K. B. Quinan, had been summoned from South Africa, on 18 December, to superintend

[1] See above, p. 26.

[2] S.R./12023/14; *Ordnance Board Minutes* 11586.

the lay-out and construction of the new T.N.T. factory. He reached England on 5 January, 1915. Pending his arrival the details of the scheme had been held in suspense, but negotiations had proceeded with the Asiatic Petroleum Company for organising a supply of M.N.T. from Borneo petroleum. An agreement had also been discussed with a well-known firm of acid makers, Messrs. Chance & Hunt, for installing subsidised plant at Oldbury to convert M.N.T. into T.N.T. These two projects eventually formed essential parts of the national scheme which materialised directly after Mr. Quinan's arrival.

By April, 1915, it was agreed that the factory to be erected by Messrs. Chance & Hunt, at Oldbury, under an agreement which was to date as from 1 February, 1915, should be run at State expense to produce between 700 and 1,000 tons of the explosive monthly. The firm was to operate the works on an agency basis. Mr. Quinan was responsible for the lay-out and efficiency of the plant, which ultimately followed the lines of the two-stage process recently evolved by the Research Department. The Asiatic Petroleum Company undertook to transfer from Rotterdam to Portishead plant for distilling toluol-benzine from Borneo petroleum, to operate this distillery and to erect near the Oldbury factory plant for treating the toluol-benzine. These works produced M.N.T. as the basic material for the T.N.T. factory. When complete they were handed over to the department's representative (Professor J. G. Lawn) and were thenceforward operated as a national factory.[1] The most remarkable feature of the scheme for national production was the speed with which it was put into effect. Constructional work began at the Oldbury T.N.T. site on 8 January, 1915; the Portishead distillery was working to its full capacity day and night by 3 April; the M.N.T. plant at Oldbury was in complete working order by the end of May. The T.N.T. plant started production in May and reached an output of 200 tons monthly by mid-July. Thus by the end of May, plant had been installed for the State manufacture of T.N.T. in quantities which even in the initial stages equalled two-thirds of the trade output and were eventually quadrupled. The practicability of operating on a large scale the economical and efficient processes worked out by the Research Department had been demonstrated. A reliable source of supply had been established under central control, and a training ground provided which was to be of inestimable use in giving the necessary experience to the works' chemists of national and commercial factories.

(b) ACTIVE MANAGEMENT OF THE INDUSTRY.

The new department's activities were not restricted to the initiation of the two national undertakings for making and purifying T.N.T. A large measure of control over commercial production was also ensured by various methods which were entirely alien to normal contracts procedure. These practices were applied in particular to the novel industry of T.N.T. production; they were less necessary in the case of picric acid manufacture, of which some experience already existed, although the practice was poor. Not only was the erection of plant

[1] 74/C/79; 95/2/73.

subsidised by the department, but engineers and chemists from headquarters and the head of the department himself paid frequent visits of inspection, advised on technical points and did all they could to hasten the work of construction. The national plant at the Research Department and at Oldbury were opened to visits from manufacturers. Every opportunity was given to individual contractors to benefit by the knowledge and experience of the department.[1]

So far as T.N.T. was concerned, about 10 new firms were engaged in erecting nitration plant during the spring of 1915, one of them (Ergite, Ltd.) contracting under the Admiralty, the rest under A.6. The supplies available from the two original contractors were immensely increased by modifications in the specification.[2]

As the new T.N.T. makers began output it became the more apparent that the knowledge and plant needed for the re-crystallising process was the limiting factor in production. To avoid purification American T.N.T. and "pellite," a crude T.N.T. produced in the dye industry, were substituted for the pure granular T.N.T. used in naval mines. It was also arranged in several cases that crude T.N.T. should be taken in place of pure, a deduction of 2d. per lb. on the contract price being generally made towards the cost of purification at Rainham.[3] An extension of this factory was sanctioned on 20 January, 1915, but its output and financial position were unsatisfactory, and a change from the original agency agreement to direct management from headquarters was effected at the end of March. The rapid expansion of the purification plant was then particularly necessary, in order to bring up to standard supplies of American T.N.T. which had begun to arrive in quantity during the previous month.

The shipments of American T.N.T. came in well to date throughout the spring; but attempts to supplement the existing contracts with fresh orders for early delivery failed, mainly because American supplies of the raw material (toluol) had already been absorbed. Moreover, competition between the Allied Governments was gradually forcing up the prices in spite of the withdrawal of the British Government from the market when such rivalry was obvious.[4] It was only by extending the date of acceptance to April, 1916, that a contract was arranged in May, 1915, by Messrs. J. P. Morgan, the War Office agents, for 2,000,000 lbs. of T.N.T. at the previous rate of a dollar per pound.[5]

Manufacture of T.N.T. began in Canada as a result of proposals made in January, 1915, by the Dominion Iron and Steel Corporation through the Shell Committee. This firm erected plant for the recovery of toluol on plans which already existed and arranged with the Canadian Explosives Company to erect and operate nitration plant at Beloeil, so that the finished product was delivered as T.N.T. to the American specification and purified at Rainham upon its arrival in England. A similar contract was arranged with the Toronto Chemical Company, which sent its whole output of toluol to Beloeil for nitration.[6]

[1] Hist. Rec./R/1500/3. [2] See below, pp. 69-70. [3] 74/H.E.T./130.
[4] Morgan Cables, London, 1002, 1003, 1066, 1072, 1079, 1089, 2129, 2169, 2573, 2644; New York, 1003, 1034, 1075, 1084, 1125.
[5] *Statement of Contracts*, May, 1915. [6] 74/D/21.

The first Canadian T.N.T. was ready for shipment on 9 June, 1915. These projects marked the beginning of the manufacture of military high explosives in Canada, the colony's production having previously been limited to the manufacture of blasting explosives by the Canadian Explosives Company.[1] All Canadian explosive orders were arranged through the Shell Committee, and subsequently through the Imperial Munitions Board.[2]

No new orders for imported picric acid were placed during the period under consideration (January to May, 1915). The extensions to existing picric acid capacity were chiefly hampered by the need for erecting nitric acid plants and by difficulty experienced in obtaining acid-resisting pottery. The picric acid plant was simpler than that needed for T.N.T.; the process used less complex; experience of the manufacturing conditions more general. Accordingly, less difficulty attended the extensions which, by the end of May, 1915, were calculated to nitrate the whole of the country's output of natural phenol.[3] Several schemes were therefore put into effect for producing synthetic phenol, an industry which was quite new in England although it had long been established on the Continent.[4] The details of these schemes are considered elsewhere.[5] In connection with them, orders were placed with certain firms for converting the synthetic phenol or dinitrophenol into picric acid. The department advanced a part or the whole of the cost of plant installed for this purpose by various firms. One contractor undertook to make the synthetic phenol and to convert it into the finished explosive. In this instance, the State bore the whole cost of the plant; the agreement was made in January, 1915, and production of the synthetic phenol began in the following July.[6]

(c) ORGANISED SUPPLY OF MATERIALS.

The department thus established national factories and exercised active control over the commerical manufacture of explosives. It was also intimately concerned in supplying the materials essential to production. The whole of the national project for T.N.T. rested upon the parallel scheme for distilling toluol-benzine from Borneo petroleum. A large part of the picric acid programme was dependent upon the production of synthetic phenol. During the first six months of the year, the measures taken in December, 1914, to acquire the whole of the country's output of toluol were brought to completion and a new source of toluol supply was added by the scrubbing of gas. Incidentally the cost of the materials was very considerably reduced. Thus, for instance, the cost of storing and refining toluol from two very considerable contracts was reduced by the committee's reorganisation of these operations from 8d. or 6½d. per gal. to 2$\frac{1}{16}$d. per gal.[7] A preliminary contract with Messrs. Chance & Hunt, negotiated early in December, 1914, rendered the Oldbury factory more than self-contained in respect to the supply of nitric acid. One of the most important

[1] X235/64.
[2] 74/H.E./1010, quoted in 74/N/113.
[3] HIST. REC./R/1500/3.
[4] HIST. REC./R/1500/14, p. 39.
[5] See Vol. VII., Pt. IV.
[6] 74/R/35, 134.
[7] X236/68.

advances made in applying the methods worked out by the Research Department in the manufacture of T.N.T. was an insistence upon the recovery and re-use of waste acids, both in national factories and by contractors.

In individual cases, the contract terms of an agreement provided for the supply of certain materials by the department. This procedure was particularly followed when the firm was new to the work. Thus the Hackney Wick T.N.T. contract provided for the free supply of toluol, oleum and sulphuric acid and the raw material (sodium nitrate) for producing nitric acid. The department also arranged to make good the Clayton Aniline Company's deficiencies in toluene, and to supply acids until the contractor's acid plant should be in working order. Such conditions were not needed in ordering picric acid from the established makers; but the production of Schneiderite, an explosive heretofore not made in England, was facilitated by the department's arranging separate contracts for the various ingredients, and the expansion of ammonium nitrate production was expedited by the department's organising a supply of calcium nitrate for the contractor concerned. The methods used in organising these supplies lie outside the scope of this narrative and are considered elsewhere.[1]

(*d*) THE PRODUCTION OF SUBSTITUTES.

The manufacture of Schneiderite was undertaken by Messrs. Curtis's and Harvey on 22 January, 1915, the day after Lord Kitchener had sanctioned experiments with this explosive.[2] The firm eventually agreed to establish at Faversham a factory to produce 50-60 (short) tons weekly, the department bearing the capital cost up to £12,000. The raw materials, ammonium nitrate and di-nitro-naphthalene were to be supplied to the contractors at a fixed price. The department placed a special order for the dinitronaphthalene with the Explosives and Chemical Products Co., Ltd.[3] With some difficulty, Curtis's and Harvey obtained from stock or at second-hand the heavy hydraulic presses needed for making the Schneiderite.[4] Their preparations were almost complete in April 1915; but the use of Schneiderite was then abandoned in favour of amatol. The Faversham works were accordingly diverted to the manufacture of 80/20 amatol blocks and the output of dinitronaphthalene was exchanged with the French Government for perchlorate of ammonia.

The actual manufacture of amatol was undertaken later in the year by the new filling factories,[5] and the gun ammunition filling authority became responsible also for supplying the filling factories with the blocks of amatol which were pressed into shape or poured into moulds, by such firms as Curtis's and Harvey, ready for insertion into the smaller natures of shell.

The production of ammonal for blasting purposes was an industry already established when the extensive use of it as a military explosive was anticipated in December, 1914.[6] A considerable order (200 tons)

[1] See Vol. VII., Pt. IV.
[2] See above, p. 11.
[3] 74/E/9.
[4] 74/C/68.
[5] See below, p. 62.
[6] See above, p. 9.

was placed on 12 January, 1915, with the established makers (Roburite and Ammonal), partly to prevent the cessation of manufacture by this firm, who were unable to obtain T.N.T. for making commercial explosives owing to the department's having absorbed the whole output of the country. By this means provision was made for engineering requirements and for emergency grenades and bombs. A contract for a much larger order, 3,000 short tons, was arranged in the following March, mainly for the Allies, but also as a provision for shell-bursters in case this explosive should have been adopted for that purpose. The department advanced the cost of the necessary extensions for the new contract and undertook to supply free of charge the main raw materials, viz., ammonium nitrate and commercial T.N.T.[1] Output under this second scheme was at the rate of 400 tons a month; but the requirements of Russia alone were for 530 tons monthly. A further contract was therefore arranged under the same conditions, raising the company's prospective deliveries to 800 tons a month. The additional plant installed included extensions at the works of two sub-contractors. The one of these, the British Westfalite Company, from their works at Denaby, co. Yorks, eventually supplied the Yorkshire firework-makers engaged upon grenade filling, and subsequently acted as agents for a bomb-filling factory adjacent to their explosives works. The other, Thames Ammunition Works, Ltd., eventually supplied ammonal for the bomb-filling factory which was erected by them at Erith and afterwards nationalised.[2] In July, these trade extensions were supplemented by the erection of a national ammonal factory at Watford.[3]

The production of ammonal for trench warfare purposes tended to release T.N.T. and picric acid for shell-filling. Large purchases of American gun-cotton for filling naval mines were intended for a similar purpose or alternatively as a constituent of the powder required by the Belgian Government. The ammonium perchlorate composition No. 30, which had been accepted for use in naval mines in November, 1914, was procured from a single contractor (Curtis's and Harvey), the raw material, ammonium perchlorate being provided by the Explosives Supply Branch. Some of this was imported from France, in exchange for di-nitro-naphthalene, some from Sweden. It was only possible to obtain the residue of the material after French requirements for aerial bombs had been met and there were diplomatic objections to an entire dependence upon Sweden for so urgent a supply. The position became particularly acute early in May, when the existing naval requirement for 400 tons was increased by a demand for another 1,400 tons for mine-filling, Offers to manufacture perchlorate explosives were invariably contingent upon the supply of ammonium perchlorate.[4] During the month of May, the whole output of the Swedish manufacturers for the rest of the year was purchased, and negotiations were set on foot for the establishment of a British ammonium perchlorate factory, which eventually materialised as a national factory at Langwith.[5] Purchases of ammonium

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[1] 74/R/8.

[2] 74/R/50.

[3] See below, Chap. IV.

[4] X236/18.

[5] See Vol. VIII., Pt. II.

perchlorate were also made from the United Alkali Company, who erected works at Flint, at Government expense, and operated them on a cost plus percentage basis on a contract dated 13 November, 1915.

IV. Review of the Position at the end of May, 1915.

The action described above had created a large capacity by the end of May, 1915, and the plant installed was in most cases expected to begin output on a very considerable scale within the next three months.

The whole capacity for T.N.T. at the end of May was 152 tons weekly. It was expected that the new plant would bring output up to 612 tons weekly by the end of July, and that the nitration plant should be sufficient to treat all the toluol available from coke ovens and gas works and from the imported Borneo petroleum. The existing capacity for picric acid manufacture produced 110 tons weekly, and new plant was expected to bring the output up to 317 tons weekly by the end of July. This included only the plant for treating natural phenol. The schemes for producing synthetic phenol were about to materialise, and provided that speedy methods of converting the synthetic product into picric acid were successful, it was expected that an additional 200 tons of the explosive weekly would be obtained from this source. The output of ammonal was 400 tons weekly; the extensions already arranged were calculated to double this rate.[1]

The recent decision to use 40/60 amatol in shells of smaller natures had not as yet affected the consumption of high explosives, since its actual use was still awaiting the adaptation of the filling plant at the Ordnance Factory. The output of ammonium perchlorate explosives was regarded as supplementary only, their general use being limited by their sensitiveness to rifle fire.[2] The total existing capacity for T.N.T., picric acid and ammonal was thus rated at 662 tons weekly; it was anticipated that this amount would be almost tripled by the end of July. It was, however, estimated that a 20 per cent. deduction should be made in all cases to allow for contingencies, including breakdown and explosion.

In the previous months of the year, *i.e.*, from February to April, the actual consumption of high explosives had fallen far below the requirements which had been estimated by the Admiralty and the War Office on the basis of contract promises for empty shell. Thus during February and March, 1915, the amount of high explosive actually used (1,039,802 lbs.) was less than a quarter of the anticipated consumption, which had been estimated by naval and military authorities at 4,505,600 lbs.[3] Great Britain had accordingly been in a position to provide her Allies with substantial quantities of picric acid, of which over 1,000 tons had already been delivered to other Governments. A stock of T.N.T., amounting to 300 tons, had also been accumulated.[4]

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[1] Lord Moulton's Memo. (27/5/15); HIST. REC./R/1500/3. [2] 74/H.E./197.
[3] HIST. REC./R/1500/2. [4] HIST. REC./R/1500/3.

During May, however, the arrival of American 18-pdr. shells entirely changed the face of affairs. Both the Royal Laboratory, where extensions for T.N.T. filling were being completed, and contractors who had begun filling shells at various dates since the beginning of the year, were consuming explosives at considerably increased rates.[1] The activities of the Armaments Output Committee[2] had already expanded the prospective demand as based on the future supplies of empty shell. The new Ministry of Munitions, announced to the public on 26 May, was about to extend the programme out of all proportion to the modest demands of August, 1914. The position was explained to the Munitions of War Committee by Lord Moulton and Sir Reginald Sothern Holland on 13 May, 1915. The general effect of their evidence was to show that hitherto high explosives had always been in advance of other munitions, but that there might be some deficiency, should the full supply of army and navy shells be obtained.[3] The methods used in developing production to meet the new circumstances are described in the chapter which follows.

[1] 74/H.E./197. [2] See Vol. I., Pt. III. [3] HIST. REC./R/172/1.

CHAPTER IV.

HIGH EXPLOSIVES: THE DEVELOPMENT OF SUPPLY (JUNE, 1915—DECEMBER 1916).

I. Expansion of the Capacity for T.N.T.

Although immense strides had been made in initiating capacity for the manufacture of high explosives, the new installations were insufficient to meet the largely increased programmes for filling high explosive shell, which were adopted by the Ministry of Munitions in the summer of 1915. From June, 1915 till June, 1916, efforts were concentrated upon the erection of new plant for supplying T.N.T. and the alternative explosives of which it was an ingredient. In the summer of 1916, the services renewed their demand for picric acid in as large quantities as possible, the construction of new T.N.T. installations ceased and the erection of large picric acid plants began.

(a) Erection of New Plant at Home.

The first step taken in increasing T.N.T. capacity was to establish a second and improved large-scale factory, which was erected at Queen's Ferry. The new project, which dated from 22 June, 1915, included the erection of a petroleum distillery at Barrow, M.N.T. works at Sandycroft, near Queen's Ferry, and of nitration plant for producing T.N.T. on the Queen's Ferry site itself, near the gun-cotton factory. The Sandycroft works were erected by the Asiatic Petroleum Company and remained for some time under their management; but one-third of the Sandycroft plant was adapted for the nitration of coal-tar toluol. The Queen's Ferry T.N.T. units were constructed as a national factory under the direct supervision of the Explosives Supply Department, being controlled from the first by Mr. Quinan, who was responsible also for the gun-cotton plant and had already designed the State T.N.T. factory at Oldbury. In the summer of 1916, when the production stage was reached, the administration of the Queen's Ferry factory was undertaken by the newly-formed Factories Branch of the department. The T.N.T. plant was projected as a national factory in view of all the circumstances of the time. The gun-cotton plant was already under State control. The size of the new factory was unique. It was considered that no private firm would be capable of dealing efficiently with the lay-out of so large an installation. The department's exertions to increase the country's high explosive capacity had already occupied the greater part of the plant-producing capacity which was of a very special kind. The employment of unskilled constructors was only likely to cause delays in erection, and add to the labour of supervision. The headquarters staff alone were in a position to supervise constructional orders with a view to all the circumstances affecting the expansion of explosive capacity. Their advantages in respect to the staffing of the factory

were similarly unique. With a view to speed, construction began and continued *pari passu* with the development of the lay-out and the preparation of drawings for plant since, while the whole scheme of the factories was thought out beforehand, the detailed specifications were necessarily treated as work began on the several units. Building contracts were therefore placed on a cost plus percentage basis, and this became an established practice in the erection of national factories for explosives.

It was intended to obtain the acids for the Queen's Ferry T.N.T. units by extending the acid plant designed for the gun-cotton production. Acid plants were therefore built on an unprecedented scale. These expanded with the growth of the factory while the oleum and sulphuric acid plants were used also as a means of supplying demands for other works. In October, 1915, a third side was added to Queen's Ferry by the designing of a tetryl plant to duplicate the Waltham Abbey installation.[1]

The second State factory for T.N.T. production was erected simultaneously with the Queen's Ferry plant at Penrhyn Deudraeth, where the works of a contractor (the Ergite Company) had been almost destroyed by explosion on 8 June, 1915. At the time of the disaster the company's factory was about to come into operation. Capital had been advanced on behalf of the Admiralty towards the original works, which were destroyed in June. In April, 1915, the Explosives Supply Branch had arranged for extensions with a view to quadrupling the factory's output. After the explosion, the company was unable to bear the cost of rebuilding. It was considered that, as a means of replacing the capacity lost, the lower cost of rebuilding the partially destroyed works outbalanced the inconveniences of adapting a partly-built plant. Accordingly the department took over the works and reconstructed them as a national factory. The situation of Penrhyn Deudraeth on the Welsh coast gave special facilities for the disposal of waste products. The peculiarities of the site enabled the new factory to be laid out for the second and semi-continuous process of manufacture which had been worked out by the Research Department; while at Queen's Ferry the first process had been adopted.

A second disaster, which occurred on 30-31 July, 1915, practically destroyed the T.N.T. plant at Ardeer, where Nobel's were making the granular form of explosive accepted for shell filling in the previous March.[2] The whole output of the factory was ear-marked for this purpose at the time of its destruction. The company did not rebuild their T.N.T. works at Ardeer, but removed the plant which remained to Pembrey, where they were erecting a second T.N.T. factory in three units on a site already acquired in November, 1914, for the manufacture of blasting explosives. It had been agreed in May, 1915, that the War Department should bear seven-tenths of the cost of the T.N.T. plant at Pembrey, the balance being paid by the company in respect of railway power and water services, which were to be common to the industrial and military factories. Arrangements were also made for

[1] See below, p. 117. [2] HIST. REC./R/1122.7/13.

the Explosives Loading Company to put up a filling factory on a part of the site. Negotiations with Nobel's for installing at Pembrey plant for the manufacture of naval and military propellants materialised after the formation of the Ministry of Munitions as an agreement to construct at government cost works for producing specified amounts of R.D.B. powder, cordite, ballistite and tetryl. The amalgamation of the various agreements made with Nobel's was discussed during October, 1915. It was estimated by the explosives finance authorities that the price asked for T.N.T. by the firm (1s. 6d. per lb.), allowed a profit of 100 per cent. on manufacture from government toluol, if no allowance were made for capital expenditure.[1] In view of all the circumstances, and particularly the large expenditure by the State on the various works at Pembrey, it was decided to nationalise both the filling factory and the explosives works. It was agreed that Nobel's should continue their responsibility for the construction of the latter and should operate the T.N.T., propellant and tetryl plants under contract until the end of 1916, the department taking the whole output during that period. From 1 January, 1917, the factory was to be worked by the firm under an agency agreement.[2] This settlement was reached in principle in October, 1915.[3] The greater part of the T.N.T. plant as originally planned had then already been erected, and the third unit had just been started, although the general progress of construction at the factory was considered slow.[4]

Several of the projects which had been committed to inexperienced contractors during the autumn of 1914 made progress which was both slow and unsatisfactory. These works were taken over by the department when partially erected and were completed and operated as national factories. The first of the factories to be so taken over was the installation at Hackney Wick, where there had been an utter failure to obtain output under the original contract of October, 1914. The disappointing results of this undertaking were ascribed by the department to the incompetence of the contractor, who had had no experience in explosive manufacture. The works were laid out at first for the French process, later, in the spring of 1915, for the Research Department's two-stage process. At the end of June, 1915, production had not yet begun. The previous agreement for the operation of the factory was, therefore, cancelled. The works were purchased by the department and placed under direct control from headquarters on 9 July, 1915. This method of acquisition was preferred to seizure under the Defence of the Realm Act, since the change in process would have rendered it difficult to enforce any penal clause and the alternative course would have involved ultimate restoration to the contractor of works in which he had invested no capital. Under the new management the factory began output at the end of July, 1915, and a second unit began work early in November, after which steady progress was maintained.

Another factory over which direct control was taken was situated at West Gorton, Manchester, where Messrs. H. N. Morris had undertaken, during the winter of 1914-15, to instal works for M.N.T. manufacture

[1] 94/T/49.
[2] Hist. Rec./R/1122.7/12.
[3] X236/89.
[4] X235/39.

side by side with a factory for the synthetic production of phenol. The progress made by these works was considered unsatisfactory. The project for making M.N.T. was converted into a scheme for T.N.T. manufacture. No phenol had been produced by the end of September, 1915, and only one lot of T.N.T., the latter falling below standard. On 7 October, 1915, the works were accordingly taken over under the Defence of the Realm Act. The T.N.T. plant was brought up to regular production, although its lay-out did not admit of economic working. It was, however, making good progress at the end of 1916.

The third installation taken over was the T.N.T. factory which had been projected by Brotherton & Co., towards the end of September, 1914, and was then intended to meet the entire demand for half-a-million pounds of T.N.T. for filling smaller natures of shell. The project materialised extremely slowly. Delivery of four and a half million pounds of T.N.T. had been promised between December, 1914, and September, 1915; but the arrears undelivered by the end of April amounted to 394,300 lbs., and in the opinion of the department the undertaking to bring so large a plant into operation in so short a time was quite impracticable. In March, 1915, an inspector was appointed to expedite work in the T.N.T. factory, which was situated at Litherland, and in the other explosive works of the firm. In the following October, it was agreed that the department's representative should become responsible for choosing and ordering the plant needed for completing the factory at Litherland and increasing its capacity from the 50 tons weekly originally intended to 100 tons weekly. This arrangement failed to produce the required result, and, accordingly, the whole of the Litherland works were taken over under the Defence of the Realm Act in March, 1916. Thenceforward, the factory was directly controlled by the department. It was reorganised during the summer of 1916, and the 50 ton output was reached in July of that year; but the plant was still ill-balanced, and regular production at the 100 ton rate was not attained until the subsequent June.

The national factories which were built for T.N.T. production were completed in the year of 1916 with the erection of an agency factory at Craigleith. These works were intended to supplement a small industrial plant which had been converted into a T.N.T. factory by the Lothian Chemical Company, and was situated on a very restricted site in the centre of the city of Edinburgh. The new site at Craigleith, outside the city, was taken over under the Defence of the Realm Act in April, 1916; the Lothian Chemical Company was responsible for the lay-out, erection and operation of the new factory, the department bearing the entire cost of building and working it. The company consisted of the Professor of Chemistry of Edinburgh University and a member of his staff, together with a works manager who had had practical experience. They had operated the Edinburgh plant with considerable success, and the initiation of the national factory under their management at Craigleith was intended as a means of utilising their skill and experience on a larger scale.

In the summer of 1916 it was decided not to erect more plant for T.N.T., but to make extensions to the picric acid capacity of the country instead.[1] While the national plant had been developed, the new T.N.T. works erected by contractors were being brought to completion. The Pembrey plant, which was erected by Nobel's at Government cost and nationalised at the end of 1916, was the only single trade venture which in any way approached the scale of the large national factories at Oldbury and Queen's Ferry. Nevertheless, the remaining two firms of the three original makers extended their works very considerably. The one (Clayton Aniline Company) nearly doubled its capacity between December, 1915, and December, 1916; and the other (J. W. Leitch & Co.) tripled its output in the same period.[2] A fourth firm of dye-makers, British Dyes, Ltd. (Read, Holliday & Co.) starting *ab initio*, erected plant for an output of 120 tons to 168 tons of T.N.T. monthly, ensuring a particularly early output by improvising nitration plant from existing nitro-benzol vessels while the new plant was being installed.[3] The remaining T.N.T. capacity created during the period under consideration took the form of comparatively small works, which were erected and operated by seven different contractors. The monthly output of these smaller plants in December, 1916, ranged between 30 and 90 tons. Three of them did not begin production until various dates in 1916.

(*b*) New Installations for T.N.T. Purification.

In organising the construction of national and trade plants for T.N.T. nitration, it was the policy of the department to insist that, so far as was possible, each factory should be self-contained in respect of the manufacture of nitric acid and the recovery of waste acids. This practice involved a considerable amount of structural work during the winter of 1915-16.[4] On the other hand, it was decided in the spring of 1915 that the new factories should not generally be built to undertake the difficult and dangerous process of purification, which was then effected by re-crystallisation from a volatile solvent, such as alcohol-benzene, or by washing in cold alcohol.[5]

The Rainham works, which had been taken over in November, 1914, failed to purify crude T.N.T. at the rate expected. The factory was planned at first to treat 12 tons weekly, and was extended early in 1915 to deal with 140 tons; but in spite of a reorganisation which took place in March, 1915, output was still less than 7 tons weekly at the end of May.[6] Until that month it had been hoped that the use of amatol would dispense with the need for purifying large quantities of T.N.T.; but artillerists insisted upon the use of the higher grade explosive in admixture with ammonium nitrate, and, in consequence, it was necessary to erect new purification plant.[7]

[1] X235/123.
[2] Hist. Rec./R/1520/17, p. 5.
[3] Sec/Gen./1176.
[4] See Vol. VII, Pt. IV.
[5] Hist. Rec./R/1122.7/13.
[6] Hist. Rec./H/1520/5.
[7] 74/Explosions/75.

The problem was laid before a firm of chemical manufacturers (Brunner, Mond) whose skilled chemists investigated various methods for expediting the treatment, being kept informed of the methods employed by the established makers (Nobel's and the Clayton Aniline Company) under guarantee that the knowledge would be used solely for government purposes.[1]

Early in June, 1915, Brunner Mond undertook to erect plant for the treatment of at least 15 tons of crude T.N.T. daily. For this purpose they first equipped a stand-by caustic soda factory of their own, which was situated at Silvertown, where output began towards the end of September, 1915. They subsequently built a new factory at Gadbrook, the construction of which began in November, 1915. The Department bore the whole cost of the works which were operated by the firm on a cost plus percentage basis. Output at Gadbrook began in February, 1916, and had reached 30 tons daily by July, 1916.[2]

The establishment of these central purification works enabled the department to take crude, instead of crystallised T.N.T., from contractors, lessening the danger risks at places of manufacture. In order to make the best possible use of capacity the explosive was taken in its pure form from those factories where purifying plant already existed; but in June, 1915, all other makers were permitted to deliver crude T.N.T. on contracts for pure, a standard deduction of 2d. per lb. being agreed about 24 June.[3]

(c) The Development of the Canadian Plant.

The projects for making T.N.T. in Canada, which began with the arrangements of the spring of 1915 for nitrating the whole of the toluol output from two factories[4], developed rapidly during 1915 and 1916. In addition to the plant at Beloeil, where the products of these two firms were nitrated, the Canadian Explosives Company undertook in July, 1915, to instal at Shand, in British Columbia, a T.N.T. plant, from which the British Government agreed to take the whole output until the end of 1916. The deliveries under all these arrangements were to the American crude specification, and therefore needed treatment in England to bring them up to the highest grades of British T.N.T. Another factory was simultaneously established at Rigaud by an English explosive firm (Curtis's and Harvey) under a contract for either the crude or the pure product. The quality of the deliveries made from this plant was of exceptionally high standard and the whole output was eventually delivered as pure T.N.T.[5] The Dominion's capacity for T.N.T. production was thus developed *ab initio* by the erection of plant which in April, 1916, had reached an output of about 150 tons weekly,[6] and six months later, stood at 250 tons weekly.[7]

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[1] 74/H.E.T./139.
[2] Hist. Rec./H/1520/5.
[3] 74/H.E.T./130.
[4] See above, Chap. III., p. 48.
[5] X235/64; 74/N/113; 74/S/176.
[6] Hist. Rec./R/1500/16.
[7] X235/64.

II. Extensions to Picric Acid Plant.

(a) Trade Extensions.

The development of new plant for picric acid production followed lines which differed from the growth of T.N.T. plant, in that the first efforts were entirely concentrated upon the expansion of trade capacity, and the erection of national factories was not begun until late in the year 1916. Very considerable extensions were made to the plant of the original War Office contractors. Other makers, such as R. Graesser, re-equipped and enlarged works which had fallen into disuse before the outbreak of hostilities. A few chemical companies were also added to the list of contractors during the autumn of 1915, and these mostly began output at various dates in the following year. The total capacity of the country was thus brought up from 31·5 tons weekly at the beginning of 1915 to 126 tons weekly at the end of 1916.

For the most part, the trade factories, when extended to the full, were still small in comparison with the large national works established for T.N.T. production. With two exceptions, viz., the works of British Dyes, Ltd., at Huddersfield, and of the Low Moor Munitions Company, the weekly output ranged between 5 tons and 45 tons in August, 1916, and was not expected to be brought above 80 tons in any single case. The advisability of spreading danger risks in this manner was emphasised by the destruction in August of the largest factory at Low Moor, which had reached a weekly production of almost 130 tons, then equivalent to more than a quarter of the whole of the country's output.[1] The only other firm whose plant had been developed on a similar scale was the War Office contractor, Read, Holliday & Co. (British Dyes, Ltd.), whose output of picric acid had been increased since August, 1914, from about 12½ tons weekly to 80 tons weekly, and was eventually brought up to 150 tons weekly.[2]

(b) National Factories.

Early in the summer of 1916 the services temporarily changed their policy in regard to the gradual abandonment of picric acid, asking for its supply in as large quantities as possible, particularly for the whole output of the 9·2-in. howitzer shell.[3] By this date (3 July, 1916), the weekly output from the trade was 400 tons and the output when all extensions were complete was estimated at 500 tons. The limiting factor in expansion was the supply of the raw material. The extensions to picric acid plant had provided for the nitration of all the natural phenol available by the end of May, 1915.[4] The large additions which had since been made were dependent upon synthetic phenol as a raw material. The steps taken to create capacity for synthetic phenol production were limited by the amount

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[1] X235/101.

[2] X235/123; Sec./Gen./1176.

[3] X235/123.

[4] Hist. Rec./R/1500/3.

of benzol which could be used for the purpose without encroaching upon the needs of the Allies. It was calculated that new plant could be erected to make an additional 250 tons of picric acid weekly without depriving the Allies of benzol. It was proposed in July, 1916, to erect the whole of this plant as a single national factory. Even thus, the output of picric acid would fall below the programme for filling 9·2-in. howitzer shell, without any allowance for the quantities needed for naval purposes and for the manufacture of certain poison gases.[1]

The original plan was to build a large national factory to produce both T.N.T. and picric acid. The T.N.T. scheme did not materialise. The picric acid factory was eventually located at Avonmouth, within easy distance of Hereford, where a new stand-by factory was being erected for picric acid filling. The Avonmouth site had been under consideration as early as April, 1916, in connection with a project for establishing sulphuric acid plant to be fed by zinc concentrates.[2] The lay-out of the Avonmouth factory included a very considerable scheme for sulphuric acid production in close conjunction with the works established at Avonmouth by the National Spelter Company for roasting zinc ore, the sulphur from the concentrates being used as the raw material for the acid production.[3] The plans for the picric acid and oleum plants were completed in October, 1916, and structural work began at once.[4] In all, ten grillo units were erected for oleum production, and a considerable part of the picric acid plant had been constructed by the autumn of 1917; but the use of the factory for the production of this explosive was then abandoned before any output had been reached, and some of the plant was subsequently converted for the production of poison gas.[5]

A more productive enterprise was undertaken at the end of 1916, with a view to utilising surplus phenol supplies which were then found to exceed former estimates.[6] Three new national factories were projected, each for a capacity of 80 tons of picric acid weekly, and each managed by a firm which had already proved itself a satisfactory contractor. Structural work began towards the end of January, 1917, at the first of these factories[7] which was situated at Lytham and managed by a contractor (Mr. Lance Blythe) who had already successfully established three picric acid works.[8] Construction of the remaining two factories, Greetland managed by Messrs. Sharp and Mallett, and Bradley managed by Major L. B. Holliday, began very shortly afterwards and good progress was made in spite of delays due to severe weather and to additional undertakings for the disposal

[1] Sir Keith Price to Dr. Addison, 3/7/16 (X235/123).
[2] X235/139.
[3] HIST. REC./R/1122.7/8; 1840/1.
[4] X235/35.
[5] HIST. REC./H/1122.7/8.
[6] (Printed) *Weekly Report*, No. 73, Sec. VII. (30/12/16).
[7] *Ibid.*, No. 77, Sec. VII. (27/1/17).
[8] *Ibid.*, No. 76, Sec. VII. (20/1/17).

of effluent.[1] Output from Lytham began in July, 1917, from Greetland in the following September; but Bradley did not actually start production until about October, 1918.[2]

The completion of these three picric acid factories marks the end of the creation of new capacity for high explosive manufacture. From the beginning of 1917, when their erection began, until the conclusion of hostilities, the main problem to be solved in supply was economy in production and self-reliance in regard to materials. Accordingly any later structural work was thenceforward intended to increase the capacity for producing raw materials, particularly for the cheaper ammonium nitrate mixtures, rather than to add to the plant for the manufacture of T.N.T. or picric acid.

III. New Plant for the Manufacture of Substitutes.

A very considerable capacity for the manufacture of amatol was established during 1915 and 1916 by the installation of drying and mixing plant in the new National Filling Factories. The hygroscopicity of the ammonium nitrate would otherwise have caused great difficulty in transporting the explosive from factory to filling station. The final stages in the production of amatol in its various forms were thus treated as part of the operation of loading and are most conveniently considered with the work of the filling factories.

In the case of ammonal for bomb-filling and other trench warfare purposes a different course was pursued. The new trench warfare filling factories were mostly built in close proximity to ammonal works. In July, 1915, arrangements had already been made to extend the ammonal plant of the established makers and their sub-contractors to the utmost limit practicable.[3] A national factory was, therefore, erected to supplement their output and provide additional explosive for the increasing supplies of trench warfare stores. The construction of the new factory began almost immediately at Watford, and a month later part of the site was transferred to the Trench Warfare Supply Department for the erection of a filling factory for trench mortar bombs.

The output of ammonal from the National Explosive Factory at Watford was intended primarily for trench warfare purposes, secondarily as a means of supplying the needs of Russia. Special arrangements were made to secure technical advice in its construction and operation from the firm of Roburite and Ammonal, to whom a royalty was paid on the explosive manufactured. The factory was subsequently used for other purposes connected with trench warfare, such as the manufacture of ophorite and smoke mixtures, and in January, 1917, upon the abandonment of ammonal as a charge for bombs and grenades, it undertook the manufacture of amatol for trench warfare purposes.

[1] X235/35. [2] 74/H.E.P./176. [3] See above, p. 51.

IV. The Financing of Construction.

(a) NATIONAL FACTORIES.

When the construction of the large national explosives factories was undertaken, no drawings of suitable plant existed, partly because of the novelty of the processes, partly because of the magnitude of the output. Neither were there available engineers who had had experience of this class of work. Serious technical difficulties arose in the course of construction, and untried methods had to be adopted in solving them. The drawings were made by competent draughtsmen at headquarters, pending construction. With a few exceptions, all steel buildings were put out to tender by the Ministry and all plant purchased by a single firm (Sir John Wolfe Barry, Lyster and Partners) on behalf of the department, after inviting competitive tender. It was not considered practicable to apply any but the time-and-line principle to the comparatively small amount of brick building done, to the lead work and the erection of internal equipment, which could not be measured in order to judge of the time it should have occupied. It was therefore agreed between representatives of the department and of the Office of Works (31 August, 1916), that the time-and-line principle was justified in this case and that the technical work of supervising construction would be too heavy an addition to be transferred to the Office of Works.[1] In nearly every instance, the building contractors were paid either a fixed percentage, or on a sliding scale, on the work which actually passed through their books, viz., wages and building materials, but not on the cost of plant, which formed a very considerable item in the expenditure on explosives works. Great difficulty was experienced in reaching any definite estimate beforehand, when works were constructed while the details of the plans were still being developed. It was not, therefore, considered practicable to base the building contractors' commission for the factories themselves upon any previous estimate of cost.[2]

Against these methods, it was argued on general grounds and in the interests of economy that the time-and-line contract, though easier to administer, led to extravagance on the part of the builder, and that difficulty experienced in obtaining estimates for repetition work when one unit had been built was due less to the contractor's unwillingness to take a risk of loss, than to the excessive profits which he made on the time-and-line principle. It is stated that, at a time when labour was extremely rare, the building contractors for one factory employed large bodies of men whom they were incapable of handling and the progress made was quite out of proportion to the numbers employed. Under constant pressure from headquarters the numbers were reduced from 4,300 to 2,000 without any apparent falling off in the work accomplished. Similarly it was alleged that at the same factory (Avonmouth), constant discussion resulted only in a slight lowering of the finish which was of too high a standard for the purpose for which the work was required.[3]

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[1] X235/35; 74/Factories/119.

[2] Sir K. Price. Evidence before Select Committee on National Expenditure, 3/7/18 (X235/47).

[3] HIST. REC./H/1122.7/8.

By March, 1919, the total capital expenditure on the national factories which come within the scope of this account, *i.e.*, those engaged upon producing the finished high explosive, had reached a total of £11,186,728.[1] This figure covers more than the cost of high explosives installations, since it includes the capital expenditure on considerable units erected for other purposes at Avonmouth, Queen's Ferry and Pembrey, and also the cost of large extensions made in connection with chemical warfare during the year 1918.

(*b*) Assisted Contracts.

Considerable grants and advances were also made to contractors towards the installation of new plant. A few of the works thus erected at Government cost were later taken over as national factories. These were Hackney Wick, Penrhyn Deudraeth and Pembrey. In other instances the department bore a part, or the whole, of the cost of constructing explosives plant which often remained the property of the contractor and occasionally reverted to the State. Much of the subsidised plant for explosive materials remained the property of the Ministry at the close of the war. In other instances, the State's contribution to new plant in explosive works took the form of a lump-sum payment. Three contractors received £10,000 each on loan, repayment being deducted from deliveries.[2] Other methods of assisting contractors, by relieving them of risk in regard to explosion and the cost of materials, will be considered later.[3]

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[1] The capital expenditure was distributed as follows :—

	£
Avonmouth*	1,578,248
Bradley	369,472
Craigleith	67,926
Gadbrook†	195,000
Greetland	183,626
Hackney Wick	66,221
Litherland	184,960
Lytham	166,774
Oldbury	835,261
Pembrey*	2,850,591
Penrhyn Deudraeth	83,015
Queen's Ferry* with Sandycroft	4,159,378
Rainham†	35,036
Watford	106,841
West Gorton	304,379
Total	£11,186,728

* Including the cost of very considerable units for other purposes than high explosive production.

† All figures, except these, represent capital expenditure down to March, 1919. These are estimated expenditure down to July, 1918, for Gadbrook (X235/47) and, in the case of Rainham, the latest figure available before the destruction of the works.

[2] (Printed) *Statement of H.E. Contracts*, November, 1916.

[3] See below, p. 137.

(c) AMORTISATION.

The proportion of the profits of the high explosives makers which was to be written off against the capital expenditure on extensions was the subject of special consideration owing to the circumstances peculiar to the industry. In January, 1916, it was agreed that all picric acid firms should be controlled under Section 4 of the Munitions of War Act, 1915.[1] The new picric acid plant for manufacture from phenol by the original pot process was considered as of practically no post-war value, since the pots and most of the buildings were unsuitable for other purposes. On the other hand, the new plant for producing this explosive from dinitrophenol was expected to be of considerable value for dye-making and similar chemical processes, provided that State protection were afforded to these trades after the war. The new T.N.T. plants were expected to have a similar post-war value contingent upon the protection of these industries. In neither case, however, was it thought that a large proportion of the plant would ever be used for commercial purposes.[2] Accordingly, it became a general practice in writing off capital expenditure against excess profits to assess the residual value of the new plant for high explosive manufacture, as well as that of its main ingredients at 25 per cent. of the actual cost. Similarly in fixing a flat-rate for the prices, both of the finished explosive and its materials, it was usual to amortise 75 per cent. of the original outlay over one year's production either of contractors' or of national factories.[3]

V. The Organisation of Supply.

The organisation of production on the scale required involved factors of prime importance quite apart from the actual construction of the necessary plant. It was essential to investigate closely new processes and methods of manufacture and to arrange for the diffusion of the latest knowledge necessary to efficient works practice. It was necessary to establish a system of training in order to provide the technical staff which would be required in large numbers to operate the new factories as they were built. In the meantime, the quality of the output could not be allowed to fall below the extremely stringent standards fixed by British naval and military authorities.

(a) RESEARCH.

During the whole of the constructive period under review an enormous amount of chemical research was needed for the finding of substitute explosives, the establishment of practicable working methods, and the planning of suitable plants. The main problems in supplying high explosives at this time was to build up from the very beginning a new organic chemical industry, to develop new processes, and train new staff while providing for safety during manufacture. Superhuman efforts were required to bridge the wide distance between the knowledge of the organic chemical industry in Germany, where its study had for years been encouraged and applied on a large scale, and

[1] HIST. REC./H/360/3. [2] X235/127. [3] HIST. REC./H/1500/4.

the scanty experience of the few British firms, who were making picric acid by primitive methods or had gained a comparatively small knowledge of organic derivatives as dye-stuffs. It is not proposed to consider in any detail the marvellous advances made in this direction. They have been more efficiently and suitably narrated elsewhere.[1] On the other hand, the methods used to obtain and diffuse the knowledge necessary for successful and efficient production were of prime importance in the organisation of supply, and belong in consequence to this narrative.

Normal procedure in peace-time assigned all investigation of chemical questions to the Research Department, Woolwich. Contrary to expectation, the chemical branch of this department was strengthened and expanded during the course of hostilities. Moreover, its activities were not confined to working on a laboratory scale. The processes for T.N.T. manufacture and the scheme for recovery of waste acids were evolved on a semi-manufacturing scale upon plant which was improvised by the department within its own boundaries.

In addition, practically all the available laboratories of the country were utilised either for general purposes or for particular investigations, often without remuneration. Offers of service from the University laboratories were accepted by the Committee on High Explosives in December, 1914.[2] The work of the Universities gradually increased in amount and importance. In 1917, the system of arranging their researches was reorganised to admit fresh bodies, and to establish systematic methods of allocating investigations, co-ordinating research and ensuring close touch with the practicabilities of manufacture.[3] The Institute of Chemistry assigned one of its laboratories for a special investigation in January, 1915,[4] and part of its premises was subsequently taken over by the Munitions Inventions Department for the study of recovery processes.[5] Guy's Hospital undertook systematic research as to the effects of T.N.T. poisoning. The Munitions Inventions Department set up various sections and committees which used expert knowledge and technical facilities in regard to diverse novel reactions and untried processes.[6]

Individual firms offered, or were invited, to concentrate upon problems for which they were peculiarly adapted by reason of previous experience, skilled staff or suitable plant. Thus a satisfactory method of producing picric acid from dinitrophenol was worked out by the firm of Holliday, at Kirkburton, during the summer of 1915, and Messrs. Brunner, Mond, developed processes for purifying T.N.T. at Winnington, Silvertown, and Gadbrook. In certain instances, the department bore the cost of experimental plant within a contractor's works,[7] and special arrangements were made for officers of the

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[1] Dr. R. C. Farmer. Memorandum on Chemical Problems in the Supply of Explosives during the War, March, 1915—November, 1918. (Hist. Rec./R/1500/14).

[2] C.H.E. Box 9, File 2584. [3] Hist. Rec./R/1500, 14, p. 10.

[4] 74/H.E./70. [5] Est. Cent./1/281. [6] Hist. Rec./R/700/17.

[7] For example, synthetic toluol plant on the premises of the Gas Light and Coke Company in 1915 (74/A/11).

department to carry out experiments on a semi-industrial scale at contractors' works.[1] At first, some difficulty was experienced in breaking down the barriers of industrial secrecy. Thus, for example, one new and efficient contractor was considerably hampered in laying out picric acid works by a refusal on the part of an existing and experienced firm to provide certain information as to the number of pots required.[2] Similarly, one of the leading British firms engaged in explosive manufacture declined to provide information as to nitric acid plant for the construction of Queen's Ferry for fear of disclosing the economic advantages of their methods to the department's technical adviser, whose services had been lent to the State by their most notable rival in the South African market.[3] This natural spirit of commercial competition, which was at first shown in a certain secretiveness, disappeared rapidly and completely.[4] As a rule, contractors showed their processes to the inspecting chemists from headquarters without much reserve.[5] Thus, for instance, the older established makers of T.N.T. provided information as to their methods of purification upon a guarantee that it should be used for Government purposes only, industrial jealousy being in this case allayed by the fact that the firm to whom information was imparted was only temporarily engaged in explosive manufacture.[6]

One of the main purposes served by the national factories was to provide the supply department with exact and practical knowledge as to high explosive manufacture. In the case of propulsive explosives, official information was readily available out of the experience of the Royal Gunpowder Factory; but the only other explosive previously manufactured by the State was tetryl. During the period under consideration, the chief service of the research work carried out at national factories for high explosives was the development of methods calculated to expedite output. The results attained were available for contractors as well as for other State factories. Makers of T.N.T., for instance, were encouraged to visit the factories at Oldbury and Queen's Ferry and to adopt the methods in use there for speeding up production. With the standardisation of process and the general expansion of output, the problems investigated concerned chiefly improvements in efficiency and economy in production.[7] These questions were from the first of considerable importance in the organisation of high explosive supply, since the programme of production from December, 1914, onwards was only limited by the materials available. They obtained additional weight with the growing stringency of the economic position and by 1917 had become of primary importance.[8]

It was the main duty of the Chemical Section of the Explosives Supply Department to collate and keep in touch with the investigations carried out by the various research bodies, by contractors and by the

[1] HIST. REC./R/1500/14, p. 9.
[2] 74/L/109.
[3] 74/Admy/7
[4] *Second* (Printed) *Report on Costs and Efficiencies*, p. 4.
[5] HIST. REC./R/1500/14, p. 5.
[6] 74/H.E.T./139
[7] HIST. REC./R/1500/14, p. 2.
[8] See below, pp. 81-84

new national factories.[1] By the spring of 1916 it had, however, been found that some more direct means of carrying out experiments was essential to the attainment of efficient results in the numerous questions which were continually arising in regard to the development both of propulsive, and high, explosives.[2] An existing laboratory was accordingly acquired under the Defence of the Realm Act at Chiswick and transferred in June, 1916, to the Office of Works.[3] The staff of trained chemists worked under the direct control of the supply department, investigating numerous technical problems in the Chiswick laboratory and carrying out experiments on a larger scale upon a semi-industrial plant, erected for the purpose within the grounds of the Grays Chemical Company, at Grays, Essex.[4]

(b) The Training of Staff.[5]

Very closely allied with the necessity for research was the need for training new staff. In July, 1915, it became necessary to provide staff for the immense new explosive factories which were being erected. It was impracticable to draw experienced men from existing private factories, which were already working at very high pressure.

The first problem was to provide trained works chemists to act as resident consultants on all matters touching production. For this purpose an informal committee, consisting of technical members of the supply department, examined candidates, and the staff bureau of the department arranged for the practical training at private works and Government factories of the chemists selected. A second difficulty arose later in the year with the need for providing large numbers of technical foremen. The normal method whereby a foreman acquired his position and knowledge after a very long apprenticeship under the supervision of trained and experienced works chemists and managers, broke down when it was applied to the process men available under the pressure of war-time production. Towards the end of 1915, a scheme was initiated for training "foremen chemists," who should have technical qualifications similar to those required in the works chemist, and should also have the soundness of health and force of character necessary for the control of a shift. The new class of foremen chemists were trained in existing factories as actual workmen, and were in fact converted from chemists to chemical engineers. After the spring of 1916, it was possible to train the men selected on the department's own plant, where they learned the latest and most economical methods of manufacture on an enormous scale.

The supply of civilian chemists suitable for training began to be exhausted in the summer of 1916. About 150 qualified chemists were accordingly withdrawn from the Chemists Brigade, R.E., and transferred to Army Reserve Class W. These men were essential to the

[1] Hist. Rec./H/1500/2.

[2] Memo. on the Establishment of Chiswick Laboratory *penes* Sir F. Nathan.

[3] Est. Cent. 1/281.

[4] Hist. Rec./R/1500/14, p. 8.

[5] Based upon Hist. Rec./R/1122.7/17. For convenience this account includes the staff in factories engaged on all classes of explosives.

starting up of Gretna, Queen's Ferry, and other smaller factories. At Gretna the plant was started up unit by unit, being first operated by experts from Nobel's while the trainees acted as supernumeraries, carrying on as the experts passed to the next unit. Still later, the same system was applied in training chemists who were brought from the Colonies, particularly from Australia and Canada.

The whole system of administration of the national explosive factories was further developed along instructive lines, which had for their ultimate object the *renaissance* of the chemical industry in England[1] and are described more fully in the chapter which follows.

(c) STANDARDISATION.

The rapid development of new capacity and the adoption of novel processes augmented the difficulty normally experienced in securing that high explosives should satisfy the standard of quality essential to stability and safety. The original limits of purity were rigidly fixed and extremely stringent in order to guard against instability during storage on shipboard or in the extensive colonies of the British Empire in tropical climates. The earliest measures taken in this respect lay mostly in the direction of modifications in the stringency of pre-war specifications to meet the urgency of the years 1914-1916. In times of peace it had been possible to obtain the small quantities of picric acid required of a very high grade in regard to ash-content; similarly the T.N.T. then used only in exploder bags was very fine, extremely pure and of very high melting-point. The result of insisting on an equally high standard when the country's resources were taxed to the utmost to supply explosives for immediate use in Europe, was to reduce seriously the rate of output and to lower the yield by considerable quantities which were lost during the process of purification. On the other hand, it was difficult to maintain so high a standard when manufacturing under the pressure of war conditions. Thus, for instance, the use of inferior sulphuric acid and the adoption of manufacture from dinitrophenol increased the average of organic matter present in the picric acid produced.[2]

Research bodies were occasionally apt to set up a purely academic standard of excellence. Design authorities, responsible to the navy and the army for the efficiency and safety of their ammunition, were loath to lower their demands as to quality. The Director of Artillery protested[3] on 6 August, 1915 that the stretching of discretionary and specification limits for high explosives was not conducive to care in manufacture which was as desirable in an emergency as in peace-time. Nevertheless, considerable modifications were, perforce, made in the interests of supply. Some of these were seriously delayed by opposition from the design authority, when the need for insistence had entirely disappeared. Thus, for five months, and at a time when every pound of T.N.T. was urgently needed for loading gun ammunition, the whole output of Nobel's Ardeer factory was refused for this purpose, on the

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[1] *Second* (Printed) *Report on Costs and Efficiencies*, pp. 4-5. [2] S.R. 16779/14.
[3] *Ordnance Board Minutes*, 15,295.

strength of a condition as to fineness applicable only to the original use of this explosive in exploder bags.[1] On the other hand, it was occasionally necessary to increase the severity of a specification in the light of experience. Thus, difficulty in connection with exudation from shells led to the raising of the setting point demanded in the crude T.N.T. which formed an ingredient of their amatol filling.[2]

As new supplies came in, certain discretionary powers were allowed to the Chief Superintendent of Ordnance Factories, and the Chief Inspector, Woolwich, in sentencing T.N.T. at the Royal Laboratory and trade filling factories respectively. Special approval of doubtful lots of American explosive was also obtained from either the Director of Naval Ordnance or the Director of Artillery; but this system was abandoned about August, 1915, since it increased labour and was hampered by differences in naval and military procedure while inspection took place before the explosive was allocated to one or other of the services.[3] Discretionary limits, were, however, generally laid down, so that the inspector of high explosives was enabled to pass doubtful deliveries for restricted purposes.[4]

The grading of all high explosives which was effected early in 1916 provided a more satisfactory solution to the problem. Both T.N.T. and picric acid were then classed in three different grades according to quality, the highest being accepted at the original contract price and corresponding deductions being made in paying for deliveries of the second or third. The best quality of T.N.T. was allocated to exploders, the second grade to gun-ammunition, and the use of the third, crude T.N.T., was restricted to mixed explosives. Similarly the first-class or "special" picric acid was for loading large naval shells in which an extremely high standard of stability was necessary; "ordinary" picric acid was ear-marked for general purposes and the third grade, or "waste" picric was either used for making poison gas or was sold to the dye industry through the Board of Trade.[5] A similar system was applied to the purchase of certain ingredients such as ammonium nitrate. Combined with the efforts of the department's inspecting chemists to raise the standard of production in individual factories, this grading of explosives had very effective influence in bringing the whole output of the country up to the excellence demanded by naval and military authorities.[6] In the case of picric acid, it also considerably increased the deliveries available for military purposes.

Steps had already been taken in December, 1915, to control the whole supply of waste picric, which could be used for dye-manufacture. During 1915, makers could obtain a higher price for the lower grade product as a dyestuff than for the higher grades required for explosive purposes. In order to prevent the consequent tendency to produce a greater proportion of waste picric than of the high-class product, control was taken in mid-December, 1915, over all dealings in this material, for which licenses were issued on the receipt of an assurance

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1 *Ordnance Board Minutes*, 12049, 13586.
2 Hist. Rec./R/1500/14, p. 6.
3 *Ordnance Board Minutes*, 15326.
4 Hist. Rec./R/1500/14, p. 6.
5 S.R. 16779/14.
6 Hist. Rec./H/900/9, p. 11.

that it was not intended for explosive manufacture. The disposal of waste picric was at first arranged in conjunction with the Board of Trade. In February, 1916, it became the business of the Explosives Supply Department alone. While supplies for every purpose were at all short, preference was given to applications for the ultimate purpose of fulfilling naval or military contracts; when the demands decreased in the following July this restriction was withdrawn.[1]

When control was taken of waste picric a flat-rate was fixed for its sale to the dye-makers, on the ground that no differentiation between purchasers would be possible. The price fixed was 2s. 6d. per lb., a sum considerably below the existing market value but still somewhat higher than the contract price for picric acid of the first and second grades. The reduction in the price of waste picric was not reflected in the price of cloth; it was therefore obvious that either dyemakers or dyers were benefiting by the difference between the market value and the charge made by the department. Accordingly the price was raised to 5s. per lb., a rate based on current offers and the price of the imported article. This rate was subsequently varied with fluctuations in the demand for the dye-industry and for the purposes of chemical warfare.[2]

The original method ("A") used in testing the quality of high explosives was to take a sample and bond the lot at works until the result of test was notified. The advantage of this system was that it eliminated any later question of returning lots or diverting them to other uses. On the other hand, it held up about 24 hours' output at works, causing grave danger and inconvenience, particularly in the factories which had been converted from industrial uses and had inadequate magazine accommodation. Method "B" was therefore introduced and became the normal system of testing picric acid and T.N.T. when makers had gained experience and the proportion of rejections had diminished. When the sample had been taken at works, the lot was forwarded at once to store or filling factory and used upon receipt of a certificate as to its quality and grading. A third system "C" was applied to works which were small and unaccessible. Their output was forwarded without bonding to the filling factory where sample was taken for analysis at Woolwich. Any of these methods would have proved cumbersome if applied to the large national factories which produced enormous quantities of high-class explosive daily. Accordingly, a system of special inspection was applied to the output of T.N.T. at Oldbury, where the managers' chemists took samples of each ton of explosive while it was being packed and the inspector checked the chemists' results by taking samples from their samples and also from the various lots. Consignments were sent forward consecutively, and without bonding, so that any lot could be returned if necessary. The explosive was, however, invariably up to specification. Modified forms of this special system were applied to other large factories, to the largest T.N.T. plant at Queen's Ferry, and to the ammonium nitrate works of Messrs. Brunner, Mond.[3] Miscellaneous explosives, such as ammonal, were inspected by means of surprise

[1] 74/H.E.P./101. [2] X/235/70. [3] HIST. REC./H/900/9, Chap. VII., pp. 6-9.

visits from chemists to the place of manufacture. All ingredients were tested beforehand and no change in process was allowed without previous notice to the inspecting chemist.[1]

The difficulty of exactly determining the degree of purity of T.N.T. increased with the extended use of lower grades in mixtures and for bomb-filling and with the decentralisation of inspection which followed the establishment of testing centres at the Universities. Discrepancies between results obtained by ascertaining the melting point of the explosive hampered manufacture and seriously inconvenienced contractors. Accordingly in July, 1916,[2] a test by setting point was devised which solved these practical difficulties.

VI. Survey of Production, June, 1915—December, 1916.

(a) Progress During the Latter Half of 1915.

The position in July, 1915, was on the whole very satisfactory in regard to the next six months. The estimated deliveries of T.N.T. and ammonium nitrate were considerably in excess of the demand as then formulated, and a slight shortage of picric acid could be met by utilising alternatives accepted for land service shell.[3]

By mid-September, the enormous increases made by the Ministry of Munitions in the programme of empty shell production had made a slight change in the position as regarded the requirements of high explosives for 1916, and had drastically altered the more distant outlook for 1917. The total demand for naval use in 1916 amounted to 24,815 short tons; for the land service it reached 70,922 tons. There was an uncertain requirement for trench warfare purposes, which could be entirely met by the use of mixed explosives. Against these quantities, the estimated supply, limited in each case by the raw material available, amounted to 58,000 tons of T.N.T. and picric acid, so that there was a deficit of 37,737 tons of high explosive if no mixtures were used. Provision had, however, been made for the supply of 100,000 tons of ammonium nitrate to be used in conjunction with T.N.T. It was calculated that the use of amatol 40/60 alone would not redress the balance and that therefore a small proportion of the 80/20 mixture would be necessary to ensure the fulfilment of the 1916 programme, and that the general use of amatol in this proportion would be essential for the satisfaction of the still greater demands foreshadowed for 1917.[4] The outlook was slightly improved by the end of September, since the success of the synthetic manufacture of phenol had raised the possible production of picric acid by 6,000 tons, and an additional 2,000 tons of T.N.T. had been secured from America. Larger purchases from this source were, however, undesirable since they had an adverse effect on the exchange and greatly increased the cost. Moreover, the limit of existing capacity in the United States had almost been reached and any additional quantities taken by Great Britain encroached upon the supply for her Allies.[5] These slight improvements were insufficient

[1] X235/16.

[2] S.R. 16779/14; *Research Department Report*, No. 26.

[3] Table, 23/7/15 (X235/166).

[4] Hist. Rec./R/1500/5.

[5] X235/166.

to make it possible to dispense entirely with the use of 80/20 amatol,[1] which was gradually adopted as a means of meeting the deficit and of economising materials as has been described above.[2]

During the latter half of 1915, and in the absence of any definite programme as to the proportions in which various high explosives could be used, the practice adopted resembled that of the previous six months, plant being provided to convert the whole of the available raw materials into finished explosive and large supplies of ammonium nitrate produced in case its use should be extended. This policy resulted in the accumulation of large reserves, since the output exceeded the capacity for shell-filling or the number of shells ready to be filled.[3] The provision of magazines therefore became a matter of critical importance during the autumn of 1915.

(b) THE ORGANISATION OF STORAGE.[4]

The only general storage accommodation for explosives was attached to Woolwich Arsenal, and consisted of high explosive magazines at Chislehurst, which were practically full by September, 1915. Similarly, for safety's sake propellants were not stored by the Ordnance Factory, but were issued as needed by the naval and military ordnance officers from magazines in the neighbouring marshes.[5] The provision of depots for storing high explosives had been considered of great importance by the Committee on High Explosives from the time of its inception,[6] and arrangements were made early in 1915 to take over cement works near the Rainham purification factory as a store for the crude and American T.N.T. which was delivered there for treatment.[7] During the summer, preparations were made for utilising Welsh slate quarries, mines at Dudley and Northwich and caves at Reigate as magazines for the comparatively small surplus of high explosive being delivered.[8] In August, the accumulation of these explosives and raw materials threatened to exceed the capacity provided, and a new problem arose out of the arrival of American propellants, for which no storage accommodation had been arranged. Obsolete forts were transferred to the supply department for this purpose ; but the surplus of high explosives continued to increase rapidly, and in October 1915, two large groups of magazines were built for propellants in order to free underground stores for high explosives. A further development in the provision of storage accommodation was the utilisation of disused brickworks, which generally met the conditions required and provided also a reliable nucleus of labour.

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[1] HIST. REC./R/1520/3.

[2] See above, pp. 15-18, 20.

[3] HIST. REC./R/1500/7, p. 6.

[4] Based, where no other reference occurs, on HIST. REC./H/1540/2.

[5] 74/H.E./565.

[6] Sir Sothern Holland to Mr. Wintour, 8/12/14.

[7] 74/C/391.

[8] 74/H.E./414.

(c) Increases in Output during 1916.[1]

The accumulation of heavy stocks continued until the autumn of 1916, as the additional plant for high explosive manufacture came into operation in advance of the new filling factories. Moreover, the policy of converting the entire supply of raw materials available into high explosive was continued throughout this year. Thus the production of T.N.T. was restricted only by supplies of toluol. Similarly, the output of picric acid, though increased by the newly-evolved synthetic methods of phenol manufacture, was still limited by the large amount of labour, benzol and acid needed for this process. Generally also, the programme for high explosive production was becoming more and more dependent upon the supply of acids, which was subjected to increasing difficulty with the growing restriction in tonnage for the enormous quantities of pyrites and nitrate of soda required for their manufacture; although the existence of stocks of these materials prevented any actual stoppage of acid production.[2]

The average weekly supply of crude T.N.T. from all sources in January, 1916, was 457 (short) tons; in the following December it was 1,522 (short) tons. The weekly rate of purification increased from 87 tons in January to 321 tons in December. During the same period the average rate of weekly delivery of picric acid rose from 224 (short) tons to 504 (short) tons, although progress was considerably retarded by the destruction of the Low Moor works in August. The production of mixed explosives advanced even more materially. Ammonium nitrate was obtained at an average rate of 370 (short) tons weekly during January, 1916; by the following December, this rate had advanced to 2,321 (short) tons weekly. The increased production of this material represented an actual advance in the high explosive available in proportions which varied with the use to which it was put. During January, 1916, 121 (short) tons weekly were used in admixture with T.N.T. for shell-filling; this figure had risen to 1,206 (short) tons by the end of the year. The remaining part of the ammonium nitrate obtained was used in making other mixed explosives for trench warfare purposes or the filling of aerial bombs. The chief of these mixed explosives, viz., ammonal, was produced during January, 1916, at an average weekly rate of 274 tons, which by December had risen to 401 tons. A rough estimate[3] of the advance in high explosive supplies, as a whole, can be obtained by comparing the total weekly output of T.N.T., picric acid and ammonium nitrate in January with that of December. In the one month this figure stood at 1,051 (short) tons, in the other, at 4,347 (short) tons, *i.e.*, in the course of the year it had more than quadrupled itself. At the same time, it should be remembered that the actual

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[1] Based mainly on a Report on the Progress of H. E. Supply and Consumption. (1/1/17), X236/34.

[2] X235/166.

[3] This makes no allowance for the 15 per cent. loss involved in the purification of crude T.N.T. affecting that small proportion of the total amount which was required as grade 1 T.N.T., nor for other high explosives, such as gun-cotton and ammonium perchlorate mixtures, not used for shell-filling.

amounts of high explosive available depended entirely upon the proportions in which ammonium nitrate was made and used in admixture with T.N.T.

In conformity with Mr. Lloyd George's instructions that production should be organised "well within the limits of Great Britain,"[1] this general advance was secured mainly by increased home production and was particularly due to the enormous strides made by the national factories as their exceptionally large plant came into operation. The home production of crude T.N.T. rose steadily from 357 (short) tons weekly in January to 909 in the following July. In August there was a drop to 766 tons; but the average weekly delivery during the last three months of the year was 1,000 tons. The rate of importation of T.N.T. varied throughout the year; Canadian deliveries in the last six months exceeded those of the first six months; imports from the United States were most considerable between March and June, fell to a few tons weekly in November, but rose again during December. The imports of T.N.T. during the former half of the year came in at rates which represented roughly 30 per cent. of the whole supply; during the latter half this proportion had diminished to 20 per cent. No foreign picric acid was purchased during the year. By far the greater part of the ammonium nitrate purchased was of British production. During the first six months of the year the quantity imported was only 308 tons, as against 15,237 tons of home manufacture. There was a slight increase in the amount imported during the last six months, viz., 3,970 tons, but the output from British plants advanced still more considerably, amounting in all to 35,798 tons.

This general progress was very largely due to the rapid development in the output of the national factories for T.N.T., particularly during the latter half of the year. During the month of December, 1915, the total output of this explosive from the six State-owned factories was 848 tons, the largest contribution being 587 tons from Oldbury. British trade deliveries for the same period amounted to 603 tons, of which 174 tons came from Nobel's Pembrey works. During the corresponding period of 1916, the national factories delivered 3,521 tons, while trade works, including Pembrey, which was about to be nationalised, produced 1,653 tons. In effect, the output of crude T.N.T. from State factories was more than quadrupled during the year, whereas that from the trade was not quite tripled. Moreover, comparatively few of the individual works owned by contractors approached the size of even the smallest of the national factories; while the output of either Queen's Ferry or Oldbury in December, 1916, was more than four times the output of the largest trade factory.

At this time (December, 1916), the construction of national factories for picric acid was only just beginning. The large advances made in home production of this explosive were therefore due to the trade enterprises which have been described above. The advance

[1] See above, p. 30.

in the rate of ammonium nitrate production was very largely due to the steady increase of output from the agency factories managed by Messrs. Brunner, Mond, at Northwich. The single State factory for ammonal established at Watford produced less than one-quarter of the whole output of the country during the year.

The use of T.N.T. for shell-filling grew steadily throughout the year, reaching its climax in October, while considerable quantities of the crude product were allocated to meet Allied demands during the first six months. At home, the rate of filling with picric acid advanced steadily, quadrupling itself during the year. The amounts of picric acid imported for Allied use remained at a fairly even figure, these demands being met in part only in view of the need for retaining some British reserve to meet unforeseen contingencies,[1] viz., the 33 per cent. to 50 per cent. margin on the actual shell programme. The rate of the consumption of ammonal advanced steadily and was more than quadrupled between January and November, falling slightly in December, and large shipments went to the Allies in June and July; but the mixing plants were not worked to their full capacity and for some time their operation was limited in order to conserve ammonium nitrate. The consumption of ammonium nitrate for shell-filling increased to ten times that of January, 1916.

(*d*) Position in December, 1916.

By the end of the year, the stocks which had accumulated steadily until the previous September, were slightly depleted. In particular, the reserves of picric acid had been drawn upon to make good the loss from the Low Moor explosion. About four weeks' stocks of this explosive was held at the end of 1916; and about eight weeks' stock of T.N.T.

The position was, however, well assured by the existence of the enormous new capacity which had been brought into being since the outbreak of hostilities. The problems of establishing a practically new industry and of bringing into operation novel types of works on an enormous scale had been solved with success. At this point the conditions affecting the supply of high explosives changed their character. Thenceforward, the main factor to be considered was economy in money and material, with the concomitant development of efficiency in methods of production.

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[1] Memo. by Lord Moulton 9/2/16; Mr. Davies to Mr. Bazire, 23/2/16 (X/235/11).

CHAPTER V.

HIGH EXPLOSIVES: ECONOMY IN MONEY AND MATERIALS (1917—1918).

I. Introductory.

During the last two years of the war, the organisation of high explosives supply resolved itself into a continuous struggle against the increased stringency of economic conditions. The growing shortage of labour, materials and money, and the general competition between all classes of munition work for priority made it impossible to continue the methods which had been adopted at the beginning of 1915. Under the new conditions, it was no longer possible to organise the manufacture of high explosives up to the utmost limit of the home-produced materials available. Grave and increasing restrictions in tonnage gave prior place to the question of acid supply, which depended upon sodium nitrate brought from South America and pyrites imported from Spain. These materials, therefore, took the place of coal-tar products as the limiting factors in supply. From the spring of 1917, when similar considerations led to the first "cut" in the programme of shell-manufacture, the steady expansion in high explosive production ceased. Thenceforward, this supply was governed by the general need for economising money and materials and the utilisation of the manufacturing capacity which had been built up followed strictly the fluctuations of the prospective demand.

II. Economies in Money.

The financing of explosive production depends to an exceptional degree upon the market rates for materials, and upon the risks incident to manufacture. About 80 per cent. of the cost of making high explosives arises out of the cost of the materials used. Hence, in this case, economy is primarily a matter of using efficient processes, saving materials and disposing of bye-products. In 1914, it had been practically impossible to check the increasing prices which were asked by contractors on the ground of rises in the cost of materials, since knowledge of processes was utterly inadequate for the purpose and no official information existed as to the minimum quantities needed for making a fixed weight of high explosive. Moreover, a market rate scarcely existed for military T.N.T. The measures taken to control the price and regulate the issue of certain materials were of supreme importance in the organisation of economical supply, and are considered in detail elsewhere.[1] The construction of national factories served a similar purpose.

[1] Vol. VII., Part IV.

(a) EFFECTS OF NATIONAL T.N.T. FACTORIES IN REDUCING COSTS OF PRODUCTION.

The establishment of large-scale national T.N.T. factories provided a means for comparing trade prices with the actual cost of production. It was recognised, in planning the factories, that the choice of process and the arrangement of lay-out according to the most advanced practice were essential factors in ultimate economy of production.[1] Accordingly, they were constructed on so large a scale as to be practically unique and they were designed and built in accordance with the most modern knowledge. Then, when operations began, comprehensive methods were established for improving the practice within the factories themselves. A detailed and uniform system of testing costs and efficiencies was applied throughout the works which were directly managed by the department. The circulation of information and the organisation of regular meetings for pooling experience encouraged competition between individual factories.[2] As a result, there was a steady improvement in usage during the whole of the year 1917, and the instructive administration of the factories reduced enormously the cost of State manufacture.[3] By the end of the year, the constant figure of toluene consumption throughout the State factories showed that little further advance could be made in that direction. Large strides had also been made in reducing the costs, and restricting the use, of acids. It was anticipated that further improvement could be made in this direction and also in regard to the service charges, which were still heavy; particularly in view of the enormous scale on which the national factories had been built. During the latter half of 1917 the average cost of production by the State was thus reduced to 9½d. per lb. of T.N.T. The average price paid to English contractors during 1916 had been 1s. 8d. per lb.[4] while, even after very considerable reductions, American prices at the close of 1916 had still remained high, being 50 cents or more per lb., and that at an unfavourable rate of exchange.

The experience gained in national factories did not apply to T.N.T. alone. It covered also the processes for the manufacture and recovery of acids, economy in which was equally applicable to the production of picric acid. The establishment of national factories for picric acid was effected too late in the course of the war for any very definite results to be attained in regard to the cost of the explosive, but it is noteworthy that the manufacture of nitric acid at one of these works (Greetland) was carried out at a rate very considerably below that of even the most economical of the earlier factories.[5]

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[1] *Second* (Printed) *Report on Costs and Efficiencies* (September, 1918), p. 4.

[2] The reports of these meetings were registered with the Factories Branch of the department and the fourteenth (February, 1918) and seventeenth (September, 1918) were printed, together with a *Report on the Statistical Work of the Factories Branch* (April, 1919).

[3] *Second* (Printed) *Report on Costs and Efficiencies*, p. 5.

[4] X 235/14. [5] *Second* (Printed) *Report on Costs and Efficiencies*, p. 11.

(b) STATE ACTION IN REGARD TO INSURANCE.

The original policy of the Ministry, and earlier of the War Office, was not to insure against fire or explosion at government factories. The earlier high prices asked by contractors were in most instances calculated to cover their indefinite liabilities in the event of an explosion, and particularly third-party risks. Contractors for high explosives were relieved of their first difficulties in regard to insurance by an arrangement made between the Explosives Supply Department and the Fire Officers' Association during the autumn of 1915.[1] As they began to realise the great extent of their liability for damages occurring outside their works, they appealed to the Ministry for protection. In certain instances, firms suggested cancelling their contracts unless the State should indemnify them against third-party risks, but were instructed to continue production in a letter drawn up by the Director General of Explosive Supply in consultation with the Chancellor of the Exchequer and the Home Secretary.[2] Again, the makers of propulsive explosives stipulated that the Ministry should indemnify them against loss by fire or explosion as a condition of a reduction in their prices negotiated during the year 1916.[3] The insurance companies had at first taken all liability except for third-party risk and workmen's compensation at a premium of £3 3s., a speculative figure since experience was limited. As a result of a serious explosion at the works of the Explosives Loading Company, Faversham, in April, 1916, this charge was raised to £5 5s., and the companies took steps to formulate a scheme defining their liabilities,[4] while the Ministry obtained Treasury sanction on 26 April to formulate a scheme for relieving contractors of explosive risks.[5] During this year delay in obtaining compensation was experienced by sufferers from certain explosions on account of difference of opinion as to whether they should be indemnified by the State or the contractor.[6] In July, Treasury sanction was given to a model indemnity clause for firms making or filling explosives provided a proper reduction in price was made in the contract price. This clause was, however, inserted in comparatively few contracts.[7] The matter became acute as the result of the destruction of the Low Moor picric acid factory on 21 August, 1916. Not only were the works wiped out of existence, but serious damage was also done to surrounding properties, including municipal works.[8] Public fear of the effect of explosions drove residents from the neighbourhood of factories and caused corporate bodies to consider the removal of their property.[9] The Ministry was aware that many of its contractors were not in a position to compensate third parties in the event of a serious explosion. Accordingly the Munitions (Liability for Explosions) Act[10] was passed in

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[1] Major Corbett Unregistered Memo., 15/10/15; 74/B/678.

[2] *Ibid.*, cf. HIST. REC./H/1500/5/8.

[3] HIST. REC./H/1530/1, p. 9; *see below*, p. 108.

[4] Minutes of Finance Committee on Economy, 17/4/16, 2/5/16 (HIST. REC./R/400/37).

[5] X 235/2.

[6] *Parliamentary Debates* (1916), *H. of C.*, LXXXVIII., 987.

[7] HIST. REC./H/1500/5/8.

[8] C.R.V./Gen./0127.

[9] Major Corbett Unregistered Memo., 1/11/16.

[10] 6 and 7 Geo. 5, cap. 61.

December, 1916, enabling the Minister to recover contributions from persons whose liability he might assume in respect of explosions or the accidental escape of poisonous gas, and to appoint an advisory committee for this purpose. The committee drew up a scheme for the indemnification of explosive manufacturers in respect of their third-party risks[1] under which the State assumed the whole liability, taking from the firm a premium to cover a part of the risk.[2] Considerable dissatisfaction arose among certain high explosive makers at the terms of the levy eventually fixed under this scheme, and was met by an undertaking that individual contracts should be reviewed where investigation might show that the levy did not enable the firm to make a reasonable profit. At the same time (May, 1918), it was pointed out that the sums charged to the contractors had not in fact covered the department in respect of third-party risks incurred since the previous June.[3]

(c) Reductions in Prices, 1917.

During 1915 and 1916 high prices had been necessary in order to encourage output. In certain instances a bonus had been paid on increased deliveries or on a product of particularly high grade for which a special demand arose upon occasion.[4] During the summer of 1917, the low costs of production established by the national factories and the stabilisation of makers' liabilities in the event of an explosion began to affect contract prices. At the same time, a series of advantageous circumstances rendered the department less dependent upon immediate deliveries from the trade.[5] The reduction in the gun ammunition programme in the spring of 1917 and the entry of America into the war strengthened the position in this respect. The wide divergence between the cost of State manufacture and the rates charged by the trade formed a good basis for negotiating reduction in several contract prices for T.N.T. Picric acid contracts were cancelled at the end of June and renewed at a flat rate of 1s. 11d., a reduction of 4d. on the price generally ruling in the previous spring. The new price was fixed in this case after examination of contractors' books, with regard to the economical use of materials and to the fact that the former high price paid had been partly intended to induce makers to extend their plant. It was subsequently recognised that a flat rate had serious disadvantages, since it was necessarily calculated to allow a reasonable profit to the small and unskilled makers, and so gave a heavy profit to the large manufacturer working well-equipped factories along the most advanced lines.[6]

(d) Advances in the Cost of Production, 1918.

The actual costs of production began to rise steadily towards the close of 1917 and continued to do so until the end of the war. The increase was particularly marked in the service charges at National Explosive Factories. These varied considerably between factory and

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1 Hist. Rec./H/1500/5/8.
2 *Parliamentary Debates* (1916), *H. of C.*, LXXXVIII., 987.
3 74/H.E.P./193; 74/S/1133.
4 X235/64.
5 74/S/1077.
6 Hist. Rec./H/1500/4.

factory, showing that large advances could still be obtained in this respect, although the efficiencies of the factories continued to improve steadily. Most of the National Explosive Factories were alike on this point, although certain of the high explosive works were subject to particularly high charges. Thus the general charges at Oldbury included the upkeep of research laboratories used for purposes outside the scope of the factory's work. The general advance in wages and conditions of labour is well illustrated by the case of Penrhyn Deudraeth, where between January, 1915, and August, 1918, the average earnings of labourers increased from 25s. to £2 15s.; of process workers from 30s. to £4 2s.; of tradesmen from £1 12s. to £3 10s.; and of lead burners from £3 9s. (January, 1916) to £4 17s. The actual cost of T.N.T. production at the national factories advanced by 1¼d. per pound during the year ending with June, 1918.[1] Nevertheless it was found practicable to make still further reductions in the prices on certain T.N.T. contracts placed in the spring of 1918.[2]

III. Economies in Material.[3]

Very remarkable progress in economising materials was made during the whole of the war both in national factories and by the trade. The general policy of supply authorities had not originally lain in the direction of complete control over the purchase and consumption of materials needed for explosive manufacture. Thus, even the powers taken under the Defence of the Realm Act with a view to enabling the War Department to acquire the whole output of toluol, were used in the winter of 1914-15 rather as a means of purchasing all the coal-tar products available than as a reason for commandeering the capacity concerned. Again, during the first eighteen months of the war, acid supplies were mainly secured by reliance upon the loyalty of makers in dealing with the demands of consumers. The consideration of the gradual restrictions which were placed upon dealings in the materials needed for explosive supply belongs elsewhere. During the year 1917, the growing limitations in tonnage led to a more definite central control over the consumption both of coal-tar products and of acids, not only by the makers of explosives but also by numerous other agricultural and industrial concerns. In this respect, a very remarkable economy in the consumption of sulphuric acid had already been achieved by the substitution of nitre cake in about a dozen important industries. This scheme, which was developed during the year 1916, effected a direct money-saving in the production of explosives, as the disposal of nitre cake, a bye-product in nitric acid manufacture, had previously been a heavy charge upon the enormous new factories. The most important steps taken towards economy of consumption in the actual manufacture of high explosives were the general adoption of improved methods and a careful and continuous supervision of works practice.

During the last two years of the war there was a distinct tendency to supplement the saving of imported materials by organising home

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[1] *First* (Printed) *Report on Costs and Efficiencies* (*Feb., 1918*), pp. 45-53; *Second* (Printed) *Report* (*Sept., 1918*), pp. 9-10, 64-78.

[2] *e.g.*, 74/S/1405; 74/S/1708.

[3] For the details of the steps taken in regard to individual materials, see Vol. VII., Part IV.

production, not only of substitute explosives but also of essential materials for which sufficient tonnage was not available. The story of these attempts is particularly remarkable, and it amply illustrates the effects of the new economic conditions upon the activities of the supply authorities. Thus a scheme for erecting plant to supplement imported sodium nitrate by deriving nitrogen from the atmosphere met with a fate very different from that of the speedily executed plans for the national T.N.T. factories erected in 1915. The project was authorised by the Minister on a small scale in the summer of 1917 and along larger lines in January, 1918. It was referred from committee to committee, each one admitting its urgency in view of the shipping position; but the actual progress of construction was delayed by the need for further reference, by low priorities and by the absolute inadequacy of the labour force. In the summer of 1918, these difficulties were further enhanced by similar claims on behalf of chemical and aircraft supply. The policy in regard to the factory was thereupon changed. Its erection was abandoned as a war measure and the whole plan was relegated to the position of a post-war scheme for industrial reconstruction.

(a) IMPROVEMENTS IN METHOD AND PRACTICE.

In considering the effects of the national T.N.T. factories upon the general costs of production, it has been seen that very large economies in the consumption of material were effected by using the most advanced methods, and by encouraging competition and the exchange of knowledge between individual factories.

Apart from the general advances made in efficiency by the national T.N.T. factories, an important change in the process adopted was effected at one of the factories, Oldbury. In October, 1917, a continuous process was started there after exhaustive research in the factory laboratories and on a semi-works scale. In regard to toluene consumption, the new method did not differ much from the process adopted in 1915 as the result of the investigations of the Research Department; but it had enormous advantages in respect to output and capital expenditure, since it went far towards enabling a factory built for 100 tons weekly to reach, with only slight structural alterations, an output of 500 tons.[1]

The initial lack of national factories for picric acid manufacture left the supply authorities without any set standards of efficiency until a very late date. The factory at Avonmouth was laid out for nitration by sodium nitrate, a method largely used in France and having the advantage of economising acids.[2] The product of this process was somewhat high in ash-content, and a special relaxation in the specification was needed to allow the prospective output to be accepted for British service; but, in view of changes in programme, the picric acid side of this factory was never put into operation. The first two of the national picric acid factories actually to produce,

[1] HIST. REC./R/1500/14, p. 107.

[2] HIST. REC./R/1500/14, pp. 72-74.

worked on a common method, viz., the nitration of phenol-sulphuric acid with weak nitric acid;[1] but their usage of raw materials varied very considerably. The less economical of them (Lytham) was accordingly closed down during a part of the winter of 1917-1918, and production there was finally discontinued in March, 1918. The other of these factories (Greetland), showed a remarkably low usage of raw materials and improved upon the efficiency of the most economical of the older factories in certain respects, *e.g.*, in nitric acid production. The last of the national picric acid factories to be built (Bradley) was planned for a different method, which was considered to be more economical than that in any existing plant.[2] The late initiation of State manufacture of this explosive, and long delays which attended the construction of the national factories which had been planned during the winter of 1916-17, gave little opportunity for application of their experience to the rapidly diminishing production of picric acid by the trade. Valuable results were, however, obtained from large scale trials carried out at Bradley and from experiments in the collection of nitrous fumes at Greetland.[3]

In regard to T.N.T. of trade manufacture, the supply department had been in a position to regulate consumption of the basic raw material, toluol, from December, 1914, when the Committee on High Explosives became the sole distributing agent of all the toluol produced throughout the kingdom.[4] The need for economy in acids grew as the war went on. In November, 1915, it was calculated that the losses of strong sulphuric acid, due to the lack of concentration plant among contractors for high explosives, were equivalent to 800 tons, while makers were complaining of short supplies. In order to prevent this " scandalous wastage," officers from the Acid Section of the department were authorised to visit explosive works with full authority to deal with acid recovery. It was laid down that all contractors should aim at self-sufficiency in respect to acid supply, and the department's officers had instructions not to allow plant to be operated unless its concentration units reached the highest standard of capacity. In many of the T.N.T. factories, insistence upon adequate recovery plant was facilitated by the responsibility taken by the department for capital expenditure upon the new units.[5] During the year 1916, active steps were taken to gather and collate information as to the consumption of acids and other materials by the trade.[6] One or two T.N.T. contractors, who had early agreements for the duration of the war, were unwilling to improve their methods. The majority made considerable advances in efficiency and undertook structural alterations for this purpose.[7] The revision of T.N.T. agreements in the summer of 1917 gave an opportunity for limiting the amount of raw materials to be used by contractors. In the common form of contract then adopted, the Minister undertook to supply raw materials at certain fixed prices. The standard of usage was defined at rates based on the department's experience of

[1] *Second* (Printed) *Report on Costs and Efficiencies*, p. 108.
[2] X237/21, pp. 8-9.
[3] *Ibid.*; HIST. REC./R/1500/14, p. 70.
[4] See Vol. VII., Pt. IV.
[5] 74/L/109.
[6] X236/67.
[7] Details are given in X237/21.

good practice. In case of an excess usage, the Minister had the option of withholding the supply of materials or charging special prices for the material used in excess of the fixed rate.[1] At the same time, it was admitted that these conditions bore somewhat hardly upon the smaller and less well-equipped factories. Accordingly, it was only possible to enforce them when the country's capacity was considerably greater than the demand and mainly as a result of the existence of the large national factories for T.N.T.[2]

The usage of raw materials by picric acid contractors had varied very considerably in 1915. Some works, for example, used sulphuric acid in the proportion of 5 units of acid to 1 of the explosive, others as 3½ to 1. Under constant pressure from the supply department there was a steady improvement in many works during 1916, particularly in the methods of collecting picric acid carried over in wash waters and in the introduction of systems for recovering waste acids.[3] During the following year, a definite effort was made towards economising materials in picric acid manufacture; but its execution was considerably hampered by fluctuations in the demand for this explosive. Frequent visits from chemist inspectors to the trade factories tended to raise the general standard of works practice, and in cases of slack control, or inefficiency, the continuous presence of the inspector secured marked improvements. The fixing of prices in a descending scale according to the grade of explosive produced had had a similar effect. Makers were encouraged to improve the efficiency of their waste acids collection, to erect adequate concentration plants for sulphuric acid and to use recovered acids for nitric acid production or occasionally for sulphonation. These measures were, however, hampered by the peculiar risks attached to concentrating the waste acids from picric acid manufacture. Similarly, insistence was placed upon the installation at picric acid works of recovery plant for nitric acid and plant for collecting nitrous fumes; but the amount of nitric acid recovered was limited even under the best conditions to a small percentage of that charged, while later experiments indicated that a large proportion of the nitrogen was practically irrecoverable. The relations between technical and inspecting officers and the contractors concerned improved generally with the course of time. Occasionally, when other methods failed, economy was ensured by starting a rationing system for raw materials. One maker's consumption of sodium nitrate was reduced in this way from 3 to 2·2 parts of nitrate to the unit of picric acid produced. Much economy was also effected as opportunity occurred by a careful reduction of the contracts with those firms whose interest appeared to lie in the direction of large output rather than efficiency.[4] Again, with the decrease in the demand for this explosive towards the end of 1917, strong recommendations were issued to contractors to instal after-nitration plant, which was established in nearly all picric acid factories by April, 1918.[5]

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[1] 74/S/1077; 74/S/1192.

[2] 74/S/1077.

[3] 74/H.E.P./176.

[4] X237/21.

[5] C.R.V./Gen./0515.

IV. Effects of the Adoption of Substitutes.

The use of substitute explosives acquired additional importance with the growing stringency of the financial and economic position. The important changes which were gradually made in the kind of high explosives used have been described above.[1] These changes were effected for two main reasons which became of prime importance during the years 1917 and 1918. They were intended (1) to render the British forces less dependent upon overseas supplies; and (2) to reduce the cost of ammunition.

(a) Expansion in the Production of Ammonium Nitrate Mixtures (1915-18).[2]

In the spring of 1915, when ammonium nitrate mixtures were first accepted in some measure as shell bursters, the country's capacity for the manufacture of ammonium nitrate was about 50 tons a week, and that by processes which were entirely dependent upon the supply of nitric acid. During the summer of 1915, orders were so placed as to bring deliveries by these methods up to 100 tons weekly, and purchases were also made from overseas. At the same time, application was made to one of the most efficient chemical manufacturers (Brunner, Mond, of Northwich) to convert Norwegian calcium nitrate into ammonium nitrate and so avoid the drain on nitric acid. Output by this method began in April, 1915. In order to avoid any further dependence upon imports of Norwegian calcium nitrate, the same firm subsequently undertook to evolve a process for manufacture from ammonium carbonate and sodium nitrate and converted existing bicarbonate of soda plant for this purpose. Considerable delays occurred in starting up this improvised plant as the process presented formidable chemical difficulties and the product was apt to fall below specification limits. By January, 1916, regular output had begun on an extremely small scale. Thereupon, it was decided to increase the rate of manufacture by extending the plant for conversion from calcium nitrate, and to avoid the risks of importation from Norway by obtaining the calcium nitrate from sodium nitrate and from calcium chloride, a bye-product of the alkali works in Cheshire. During the year 1916, extensive plant was erected and adapted both for the production of the calcium nitrate and for its conversion into ammonium nitrate. The ammonia soda process was continued alongside the new method of manufacture and was facilitated by the grading of ammonium nitrate into three classes, the two lower ones embracing the product of the ammonia soda process.

Between October and December, 1916, with the extension of the gun ammunition programme and the general acceptance of 80/20 amatol, new plant was projected for manufacture from calcium nitrate. Before the scheme had materialised, it had, however, been proved practicable to make ammonium nitrate directly from sulphate of ammonia and sodium nitrate on a commercial scale. In consequence,

[1] Chap. I. [2] Based on HIST. REC./H/1520/2, 4, 14.

the plan for the new factory was abandoned in favour of a national factory, which was erected at Swindon along lines calculated to save 50 per cent. of the cost and labour previously estimated. By November, 1917, the output of ammonium nitrate at home had risen to 3,000 tons per week and was likely to increase by another 1,000 tons when the initial difficulties of starting up a new plant had been overcome at Swindon.[1] Dependence on overseas supplies had diminished steadily owing to the construction of the Northwich units. In 1915, purchases of ammonium nitrate from abroad represented 14 per cent. of the total deliveries; during 1916 and 1917, they had fallen to 8 per cent. In 1918, they again fell to 2 per cent. of the whole supplies.

The combined deliveries of ammonium nitrate from home and foreign sources increased steadily until December, 1916. Output, thenceforward, varied with the changes in programme, reaching over 3,000 tons weekly in June, 1917. These advances resulted in a certain amount of over-production in the spring of that year,[2] but enabled large quantities to be provided for the Allies, particularly for Russia, 1,700 short tons being so issued between January, 1917, and November, 1918.[3]

The supplies of ammonium nitrate reached their climax with a weekly delivery of 4,000 tons in March, 1918. From the spring of 1916 onwards, they had invariably exceeded deliveries of either T.N.T. or picric acid, and the difference increased widely as time went on and the economic advantages of ammonium nitrate mixtures in regard to cost and tonnage became of greater importance.[4]

(*b*) Utilisation of the Capacity for Trench Warfare Explosives (1917-18).

The arrangements made for producing trench warfare explosives during the year 1915 had included provision for the manufacture of ammonal and also of various miscellaneous explosives, viz., alumatol, "sabulite" and "abelite," which were less efficient or less safe than ammonal. The actual consumption of these miscellaneous explosives was on a very limited scale and the reduction in demands for trench warfare purposes during 1916 was followed by a cessation of their manufacture, leaving certain stocks in hand.[5] Early in 1917, the use of ammonal was also abandoned in order to economise aluminium, the price of which had risen from £81 per ton in January, 1915, to £300 per ton in November, 1916.[6]

After January, 1917, amatol became the standard high explosive for trench warfare purposes and for aerial bombs. Its production for this purpose was undertaken by the factories previously making ammonal, and in December, 1917, one of the sub-contractors under Roburite and Ammonal (British Westfalite Company) entered upon a direct agreement with the department for re-treating the stocks of

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[1] X/236/29.
[2] X/235/35.
[3] Hist. Rec./R/1010/32.
[4] See above, p. 21.
[5] X/235/21 : 74/S/218.
[6] X/235/13.

sabulite for trench warfare purposes. This work was also undertaken temporarily by the Watford national factory, which occupied the remainder of its capacity in making smoke mixtures and various special charges and in re-conditioning recovered explosives.[1]

In January, 1918, the preparation of finely-powdered T.N.T. suited for the special 80/20 mixing plant at the Chilwell Filling Factory was temporarily undertaken by the Watford Explosives Factory and also by Messrs. Roburite and Ammonal, whose capacity by the end of March sufficed for the entire demand. This requirement had previously been satisfied from purified T.N.T. and later from powdered "Triton" purchased from America.[2]

(c) THE CLOSING DOWN OF PICRIC ACID FACTORIES, 1918.[3]

The gradual disuse of picric acid during the last year of warfare was entirely based upon reasons of economy, viz., the saving of tonnage for sodium nitrate, the saving of man-power by closing down the synthetic phenol factories, the release of benzol for use as motor spirit or as a solvent and the saving of money. It was estimated that on the 1918 programme alone the substitution of 80/20 amatol for picric acid would effect a saving of two-and-a-half million pounds.[4]

On the other hand, the abandonment of the high explosive which had for many years been the standard bursting-charge in the British services entailed the closing down of very considerable plant, which had been erected for the manufacture of the explosive and its materials or for the filling of shell by the melt process. Steps were taken at the beginning of 1918 to cancel all trade supplies of picric acid except those from three firms, two of whom had contracts which were for the duration of the war. Their deliveries, together with those from the most economical of the four national factories (Greetland), sufficed for the limited demand for naval and special purposes and to maintain a reserve in case the destruction of amatol filling plant should enforce the resumption of lyddite filling. With one exception, the synthetic phenol works, which had been constructed solely for the purposes of the war, were closed but kept available for restarting in case of need. The capital expenditure by the State on plant which was left idle, exclusive of the filling plant, had then amounted to rather more than £1,700,000, and in two cases (Avonmouth and Bradley) had been incurred for units which had never been in operation.[5] The cessation of production was effected gradually in order to minimise the dislocation of labour; but this was relatively slight as it was possible to transfer operatives to other factories.

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[1] X/237/21.

[2] *Ibid.*

[3] Based on 74/H.E.P./193.

[4] M.C./372.

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Bradley	£360,000
Lytham	180,000
Avonmouth (picric acid section)	300,000
Ellesmere Port	140,000
Sutton Oak	114,000
West Gorton	102,500
South Metropolitan Gas Co.	504,000
	£1,700,500

The arrangements thus made for maintaining a relatively small output (300 tons weekly) of picric acid and a substantial reserve in case of emergency served their purpose until the cessation of hostilities, although in October, 1918, the alternatives of restarting one of the idle factories or purchasing from America were under discussion, mainly as a means of meeting the needs of the Allies and of Italy in particular.

(*d*) ORGANISATION OF THE SUPPLY OF AMMONIUM PERCHLORATE MIXTURES (1918).

While active steps were taken during the years 1915-17 to ensure an adequate reserve of ammonium perchlorate, in case the Admiralty should extend the use of mixtures in which it was the main ingredient, the plant for mixing the ammonium perchlorate with other substances was restricted to the comparatively small capacity needed to meet naval demands for mines for certain special purposes. Two contractors were engaged, the one in making R.D. Composition 30, the other, R.D. Composition B. Together they could deliver 50 tons per week in January, 1918, and their output was expected to reach 75 tons per week by the end of March. The only other finished perchlorate explosive supplied was "blastine," of which moderate quantities had been purchased from a single contractor for the use of the Royal Engineers, until June, 1917, after which this firm undertook the manufacture of composition B.

Towards the end of the year 1917, the Admiralty had been pressed to accept large quantities of ammonium perchlorate mixtures for mines, since they could be made almost entirely from British products; and the adoption of these mixtures for aerial bombs was also under consideration. Pending a decision, the supply department projected a third mixing factory with a capacity of 70-80 tons weekly to be erected at Weston-super-Mare,[1] but the scheme was left in abeyance until it should have been established that a larger demand would arise than could be met by the two existing contractors.[2] The extended use of perchlorate explosives was still under discussion at the end of the war.[3]

V. Review of Output, 1917-18.

The first three months of the year 1917 were chiefly noticeable for a steady increase in the output of high explosives. Special efforts were made to replenish the reserves of picric acid which had been greatly diminished during the winter, and home supplies of this explosive were supplemented by considerable purchases from the United States and France.[4] Deliveries of T.N.T. increased steadily by reason of the adoption of the continuous process at Oldbury and the balancing of acid and nitration plant at other factories. At the end of February the output of T.N.T. aimed at was 1,600 tons weekly from the following July.[5]

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[1] D.M.R.S. 505/A/1. [2] X/237/21. [3] See above, p. 19.
[4] X/237/21. [5] X/237/31.

(a) EFFECTS OF THE REDUCED GUN AMMUNITION PROGRAMME, MARCH, 1917.

The reduction of the filling programme in March, 1917, was met by a partial cancellation of the scheme for the Avonmouth picric acid plant and by an increase in the use of 80/20 amatol.[1] Construction of one of the three units at Avonmouth was abandoned altogether[2]; but deliveries of picric acid were allowed to increase until June, 1917, partly to replenish stock, partly to provide for the urgent needs of the Allies. By June a sufficient reserve had been built up. All British picric acid contracts were then cancelled and renewed for diminished quantities at reduced prices. During the following three months the consumption of picric acid was, however, greater than had been anticipated, and by mid-August the stocks were entirely exhausted save for some 800 tons held by the filling factories.[3]

Deliveries of T.N.T. continued to exceed consumption by considerable quantities, reaching their maximum of over 2,000 tons in the first week of April, 1917. Thenceforward definite steps were taken to diminish the supply by ceasing to purchase in the United States, by reducing the home production and by modifying the arrangements with Canadian manufacturers.

In decreasing trade supplies, it was decided in June, 1917, to cease manufacture at once at works situated in congested districts or those dye-works which, by reason of the improvised nature of their explosive manufacture, were unsuited for license by the Home Office. This decision was taken in view of the destruction of a contractor's T.N.T. factory at Hooley Hill and of the repeal of the Order exempting T.N.T. from the Explosives Acts which was then pending as a result of the Silvertown explosion in the previous January.[4] The opportunity was taken to reduce contract prices as from June, 1917, as has been already narrated. Four contractors only for T.N.T. were retained from that month with a total weekly capacity of rather more than 100 tons,[5] but temporary arrangements were made with others to keep their plant available in case of emergency. The State factories were relied upon to produce between 750 and 850 tons, and to be ready to keep the balance in case of any future change in programme. American shipments, which were still coming in at about 250 tons weekly in July, were regarded chiefly as a margin, in view of the uncertainty of shipping, considerable quantities of T.N.T. having been lost at sea.[6]

These drastic decreases in the trade output were arranged during June, at the end of which month most of the existing contracts expired. Two of those which were continued were of early date and had been made for the term of the war. The output from State factories had already been decreased at the end of April, when two (West Gorton and Pembrey) were entirely closed and others (Queen's Ferry and Oldbury) kept part only of their capacity under operation.[7]

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[1] A.C./71.
[2] 74/Avonmouth/68.
[3] X/237/21.
[4] 74/Explosions/75; 74/H.E.T./379; X/237/21, p. 18.
[5] X/235/64.
[6] 74/H.E.T./386.
[7] (Printed) *Weekly Report*, No. 88, VIII. (21/4/17).

The main effect of the reduction in programme was to free the department from any further dependence upon overseas supplies of finished high explosives.[1] Apart from the picric acid purchased early in 1917 in order to replenish stocks, no further supplies of this explosive were bought for the British army from abroad. Arrangements were, however, made that the British Government should negotiate the purchases in the United States of supplies of picric acid needed for filling American shell in Canada. Similarly, the T.N.T. contracts in the United States and Canada were not renewed. It had been intended towards the end of 1916 to render the British Empire self-contained in regard to high explosives. For this purpose, acceptance had been given in November, 1916, to an offer from a Canadian firm acquainted with nitro-products, who proposed to erect T.N.T. plant at Trenton, Ontario, and operate it as a State factory under the Imperial Munitions Board, using toluol obtained from the United States.[2] The first intention of using the output of this factory to supplement British manufacture was modified to meet difficulties of exchange which arose during the spring of 1917.[3] Accordingly, after deliveries amounting to considerably less than 2,000,000 pounds of T.N.T. had been accepted, the output was diverted to the Italian Government, to whom it continued to be allocated until the destruction of the factory in October, 1918.[4] In this way, imports which had formed an important part of the whole supply of high explosives during 1915, and a considerable supplementary amount during 1916 and the first half of 1917, were entirely abandoned from October of that year until the cessation of hostilities.

(b) Increased Programme for 1918.

The restrictions in manufacture at home and the abandonment of imports from America had scarcely been brought to their full effect when in October, 1917, the supply of high explosives again became a matter of extreme urgency, and the maximum home output was once more required.[5] All demands put forward for 1918 in the autumn of 1917 exceeded the consumption of that year by very large amounts. A general expansion was anticipated in the filling of land service shell, trench-mortar ammunition, grenades and aerial bombs. In addition to other increases in the naval programme, large quantities (5,000 tons) of T.N.T. were needed for "destructors" by the end of May, 1918.[6]

The new position was governed almost entirely by the supply of raw materials, particularly sodium nitrate and pyrites for acid manufacture and Borneo petroleum from which about half the toluol supply was derived. Enough benzol was available to satisfy the British demands for picric acid manufacture and allow even more towards Allied requirements; but the maximum deliveries of T.N.T., based on the amount of toluol available, fell far short of the programme as set out in November,

[1] D.M.R.S. 555.
[2] 74/D/344.
[3] X235/105.
[4] R.I.M.B./Gen./221; D.E.S. 2/13.
[5] X235/2.
[6] 74/Admiralty/87; D.M.R.S. 505/A/1.

1917.[1] Overseas purchases were still prohibited by the restriction of tonnage and by exchange difficulties. The chief method employed in meeting the new programme was an increased use of substitute explosives, especially of those which involved the least importation of raw materials.[2] Nevertheless, stocks of sodium nitrate and coal-tar toluol were gravely depleted, the one by reason of shipping difficulties, the other mainly on account of shortage of labour.[3] The deficit in sodium nitrate was borne by abandoning picric acid from January, 1918, onwards.[4] The T.N.T. position was somewhat eased by a renewed reduction in the shell-filling programme in April, 1918.[5] It was also possible in the spring of the year to reduce the production of ammonium nitrate.[6]

(c) UTILISATION OF SPARE CAPACITY IN 1918.

The most remarkable feature in the organisation of the country's high explosive capacity during 1918 was the conversion of plant for the manufacture of poison gas. Until the spring of that year the manufacture of explosives and of lethal or lachrymatory chemicals had been practically independent of each other, except that the need for waste picric for making P.S. had been one of the causes leading up to the purchase of all classes of picric acid in 1916. The decreases made in picric acid production during the first few months of 1918 resulted in a deficit of the waste picric suitable for this purpose. Accordingly from April, 1918, onwards, this demand was met by supplies of service picric acid provided from the Greetland national factory without drying.[7] The transfer of administrative authority over the production of chemicals to the Explosives Supply Department in April, 1918, facilitated economy of capacity by enabling picric acid plant, set free by the abandonment of that explosive, to be diverted to the manufacture of poison gas. The synthetic phenol plant at two national factories (Sutton Oak and Ellesmere Port) was utilised for making certain poison gas ingredients from June, 1918, onwards, beginning bulk production in the following November. The picric acid plant at Rainham Ferry was used for a similar purpose and one picric acid contractor, at least, undertook to make the same ingredient, but with little success. The most important of these enterprises was the scheme for converting the plant at Avonmouth into a factory for the manufacture of mustard gas. On 15 June, 1918, decision was taken to manufacture this gas at Avonmouth for charging at Chittening[8], and production began there on 11 September, 1918. Shortly before the Armistice it had also been intended to utilise a part of the site of this factory for new national plant for the production of C.G., but this project had not materialised when hostilities ceased.

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1 X236/29. 2 See above, p. 19.

3 (Printed) *Weekly Report*, No. 139, Section V. (27/4/18).

4 HIST. REC./R/1500/11 ; X235/2.

5 (Printed) *Weekly Report*, No. 139, Section V. (27/4/18).

6 Departmental Minute, 129. (X235/2).

7 (Printed) *Weekly Report*, No. 138, Section V. (20/4/18.)

8 D.E.S./Chittening/22.

CHAPTER VI.

PROPULSIVE EXPLOSIVES: NAVAL AND MILITARY SUPPLIES (AUGUST 1914—MAY 1915).

I. Position at Outbreak of War.

When war broke out, the normal sources from which supplies of propulsive explosives were drawn for the navy and the army were the Royal Gunpowder Factory, Waltham Abbey, and seven British trade factories.[1] The weekly capacity of the Royal Gunpowder Factory was 30 tons, capable of increase to 72 tons by the substitution of continuous work for day-shifts. The total weekly capacity of the seven explosives firms was 100½ tons on day-work, or 193½ tons working continuously. In addition, an eighth firm, Kynoch, Ltd., had plant for 25 tons of cordite weekly. This firm had received no government orders for some years, but, shortly before the war, had entered upon arrangements for re-starting upon War Office orders. Thus the maximum existing capacity of the country for cordite manufacture in August, 1914, was 290½ tons weekly.

Upon the outbreak of war, the Admiralty gave instructions to all firms to produce the maximum quantity possible from existing plants. The rifle cordite plant at Waltham Abbey was extended under orders given by the War Office in the second week of September. The new plant had a capacity of 20 tons weekly. It began production 1 April, 1915, and reached its maximum output by 15 May.[2]

II. Extensions for War Office Requirements, October—November, 1914.

During October and November, 1914, steps were taken to provide largely increased quantities of cordite for the land service. An immediate supply was obtained by the transfer to the army of 1,000 tons of naval cordite, to be produced by existing plants between November, 1914, and March, 1915, when the trade capacity from which it was allocated would revert to Admiralty orders.[3] Mr. Churchill, then First Lord, agreed to this arrangement on 14 October, at the same time pointing out that it was a matter of general policy rather than one for his own decision, and that it would disarrange seriously the long-prepared plans of the Admiralty.[4] Provision for the army's increased requirements in 1915 was made in part by a War Office scheme (12 October) for expanding the capacity of the ordnance cordite plant at Waltham Abbey to a total of 120 tons weekly. The plant began production on 24 June, 1915, and reached its full output in the following September.[5]

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[1] *Viz.*, British Explosives Syndicate, Ltd., Chilworth Gunpowder Company, Ltd., Cotton Powder Company, Ltd., Messrs. Curtis's and Harvey, Ltd., National Explosives Company, Ltd., New Explosives Company, Ltd., and Nobel's Explosives Company, Ltd.

[2] Hist. Rec./R/1122.12/1.

[3] Hist. Rec./R/1530/1.

[4] Hist. Rec./R/1500/12.

[5] Hist. Rec./R/1122.12/1.

Arrangements were also made to increase very considerably the trade capacity for cordite manufacture. Negotiations were set on foot by the War Office with Nobel's for the erection of a new, self-contained factory to be subsidised by the State. The company had stipulated that the capital expenditure should be refunded by the Government within one or two years and that the factory should not revert to the State.[1] It was arranged early in November, 1914, and in accordance with Cabinet instructions to the War Office that Nobel's should erect at Misk, near their Ardeer factory, plant for producing an additional 300 tons of cordite monthly to which the Government was to contribute £300,000 on the ground that none of the plant would be needed by the firm in time of peace.[2] The firm added, at its own expense, plant for 28 tons of rifle cordite weekly. Production began in April, 1915. The War Office also took measures to extend the capacity of five other cordite firms, Kynoch (under two schemes), Curtis's and Harvey, British Explosives, the New Explosives, and the Cotton Powder Companies, by subsidising plant which should begin output between March and May, 1915.[3] The Indian Government also agreed on 17 October, 1914, to provide from the cordite factory in the Nilgiris certain monthly quantities over and above the requirements of the Indian Army, but subject to the exportation of acetone, glycerine and mineral jelly from Great Britain for the use of the factory.[4]

III. Extensions for Admiralty Requirements, December, 1914—January, 1915.

Any Admiralty measures for extending the capacity for naval cordite production were postponed on 12 November, 1914, pending the Board's decision as to the requirements. It was agreed that naval and military authorities should then ascertain in conference whether the extensions which were being arranged for military purposes would also cover naval requirements. Failing this, it would be necessary for the Admiralty either to begin erecting a government factory or to arrange for further trade extensions. Upon re-consideration of the position about 15 December, 1914, it was found that there would be a deficit of naval cordite amounting to 3,600 tons by the end of 1915.[5]

The First Lord decided on 15 December, 1914, that this deficit should be met by further expansion of the trade capacity, subsidies being made contingent upon the retention of the new plant by the State at the close of the war. Negotiations were authorised for extensions for a total output of 300 tons monthly with three firms, and for another 300 tons monthly to be produced by a fourth (Nobel's) from new plant. Production was expected to begin in June or July, 1915. Treasury sanction was given at a meeting of the Treasury Emergency Committee on 19 December, 1914.

Conferences were held between Admiralty and War Office representatives and others to consider future supply.[6] The first of these meetings took place in the First Lord's room at the Admiralty on

[1] C.P. 82066.
[2] *Ibid.*
[3] HIST. REC./R/1530/1.
[4] HIST. REC./H/1530/1; see also 74/6/3596.
[5] Based on C.P. 89166; C.P. 101881/14.
[6] C.P. 101881/14.

24 December, 1914. At subsequent meetings Nobel's Explosives Company were represented. On 28 December, Lord Moulton came into conference, since he was anxious that the proposal to extend Nobel's cordite capacity should not interfere with the arrangements which were being made by the Committee for the Supply of High Explosives for establishing a T.N.T. factory at Pembrey. The site at Pembrey had been acquired by Nobel's about November, 1914, for the purpose of erecting works for industrial explosives, which had originally been projected for a site on the Isle of Sheppey. At the conference of 28 December, the possibility was discussed of building at Pembrey a new cordite factory to produce 600 tons monthly from July, 1915, onwards. Nobel's representatives only considered it possible to have plant for 200 tons monthly ready by September, 1915. This could be followed later by plants for an additional 400 tons monthly. Production could be expedited by using American guncotton.

In the first week of January, 1915, definite authority was given to the three firms named above to increase their output by a total of 300 tons monthly in view of the exceptional urgency of the position. The Admiralty deficit anticipated by the end of the year was then 9,075 tons, the greater part of the shortage (7,251) falling between the months of July and December. The projects for meeting the estimated deficit covered only about 5,700 tons, and that at an expenditure of £1,410,000 and contingent upon the use of American guncotton. The position was the more serious because the cordite firms and plant manufacturers were already endeavouring to reach an output from ten to twelve times as large as their peace-time production, which was normally about 3,000 tons a year. The action taken by the War Office included negotiations with Kynoch's for further extensions involving the erection of new plant for making military cordite at Kynochtown in Essex, out of nitroglycerine from Arklow in Ireland, and guncotton from Umbogantwini in South Africa.[1]

Normally, cordite factories were self-contained in respect of guncotton production, but the erection of this class of plant threatened to be delayed. Attempts were accordingly made to purchase guncotton from America; but it proved unsatisfactory in quality. A small guncotton factory at Colnbrook was also extended to supply the Belgian, as well as the British, forces. These works, however, had not reached a satisfactory output by June, 1916, when they were taken over and operated as a State factory by the Ministry of Munitions.

IV. Scheme for Erecting the Royal Naval Cordite Factory.

Negotiations with Nobel's as to the proposed factory at Pembrey were obstructed by two difficulties, viz., the high terms asked by the firm[2] and the entire dependence of the scheme upon the suitability of American guncotton for naval cordite production, a question not then settled. Guncotton plant could not be erected at Pembrey before

[1] Hist. Rec./H/1530/1. [2] C.P. 101881/14, 18727/14, 165/15.

September or October, 1915. Lord Moulton could promise no prospect of Government production of guncotton, hence, failing the American guncotton, a large expenditure would be incurred for a very small output in 1915. Early in January, 1915, it was agreed that even this risk must be taken. No definite agreement was made with Nobel's till the position as to American guncotton had been ascertained; but authority was given to the firm to accept an offer of 800 tons of guncotton from the du Pont de Nemours Co.[1] Towards the end of the month it was decided, on expert advice, to use this material for mine filling rather than for the manufacture of cordite.[2] Accordingly, at the beginning of February, 1915, the project for subsidising a factory at Pembrey to convert American guncotton into cordite was abandoned in favour of a scheme for a national cordite factory under Admiralty control.

The establishment of such a factory under Admiralty control had been favourably regarded by certain naval authorities in the previous autumn and was one of the reasons for insistence upon the reversion of subsidised plant to the Crown.[3] The decision taken against the use of American guncotton reduced to 2,200 tons only the additional output arranged to meet an expected deficit of about 10,000 tons. The First Lord considered that the late date at which alone Nobel's would be able to start, since the erection of guncotton plant was involved, made the scheme for the Pembrey factory an extravagant method of action, and that the money could be put to better use by starting a naval factory under Admiralty control. He accordingly asked for proposals to be submitted to him with the least possible delay for erecting an independent naval factory to produce cordite at the rate of 400 or 500 tons a month from June to July, 1915, onwards.[4] Other reasons adduced for the establishment of a separate naval factory for guncotton and cordite were that the construction of plant for 400 to 500 tons monthly would need exceptional measures and a specially concentrated effort; the technicalities were complex, necessitating control by one head; the War Office was engaged on similar operations and considered that when extensions then in hand at Waltham Abbey were completed the limit for that factory's expansion would have been reached. Makers of plant were very full of orders. In particular, great difficulty had already been experienced by Nobel's in initiating the Misk factory both in obtaining skilled labour and on account of the congestion with firms producing plant of the required type. Sir George Gibb undertook (28 December, 1914) to approach the Board of Trade for assistance in providing skilled plumbers for this work.[5] The Director of Naval Ordnance expressed his opinion, on 28 January, 1915, that the only prospect of success lay in the control of the undertaking by a special temporary staff under his supervision and with the necessary technical aid from other members of the Department.[6] He submitted a scheme on 28 January, 1915, for setting up a

[1] C.P. 15332.

[2] C.P. 13233, G. 0203. The order for guncotton was subsequently cancelled by arrangement with Nobel's.

[3] On C.P. 29351; C.P. 82066.

[4] C.P. 101881/14.

[5] *Ibid.*

[6] *Ibid.*

guncotton and cordite factory on the scale laid down by the First Lord. He proposed that it should be built along the lines of Waltham Abbey; that the loan of technical experts should be asked from the War Office; that the buildings should at first be light, but in the event of a decision in favour of retaining the factory after the war these could gradually be re-built; that, in this case, orders would still have to be placed with the firms who had laid out capital on new plant; and that it would be necessary to establish a system for purchase of ingredients to avoid clashing with the War Office. A scheme for erecting a State factory was outlined at a meeting under the presidency of the Civil Lord on 12 February, 1915, and the expenditure sanctioned for the factory to be erected by Nobel's was allocated to this purpose on 24 February. The project eventually materialised as the Royal Naval Cordite Factory at Holton Heath, near Wareham, Dorset.[1]

V. Action Taken to Expand Production, January—April, 1915.

The projects for co-ordinating the action taken by the Admiralty and the War Office towards extending the country's propellant capacity have been described above.[2] The main result of these efforts was the construction of a guncotton factory at Queen's Ferry, and the renewal of negotiations with Nobel's for erecting a cordite factory at Pembrey. The completion of the Royal Naval Cordite Factory was expected by the end of the year. Further trade extensions, organised on behalf of the Admiralty during the months of March and April, were expected to begin output in the following September. At the beginning of May, it was estimated that these, with the Royal Naval Cordite Factory, would bring the existing capacity for naval cordite from 400 tons monthly up to 2,870 tons monthly by the beginning of 1916. There still remained a considerable deficit in the output for the navy during the latter half of the year. On the other hand, the combined extensions at the Royal Gunpowder Factory and by the trade were considered to be almost equivalent to the production of land service shell as then anticipated. Any further extensions along the same lines were hampered by the limited quantities of acetone available as a solvent for cordite manufacture. The use of a single-base propellant, such as the nitrocellulose powder made in America was consistently rejected by the naval authorities on the ground of instability; but steps had already been taken by the Army in October, 1914, towards supplementing home supplies by purchases from abroad.

VI. Overseas Supplies.

On 17 October, 1914, an agreement for overseas deliveries had been made with the Indian Government. It was arranged that the surplus output from the cordite factory in the Nilgiri Hills should be taken for the British Expeditionary Force. Rather more than 70 tons were delivered during the next 10 months; but the factory's production was hampered by delays in importing raw materials and

[1] On C.P. 101881/14; C.P. 21107.

[2] See above, p. 28.

decision was taken in June, 1915, against extending the Indian cordite capacity[1]; its surplus output was however taken till the end. of the war.

The possibility of obtaining cordite from Canada had also been considered in October, 1914. There was then only one Canadian firm engaged in the manufacture of military explosives,[2] and its capacity was already being extended to provide cordite for the complete 18-pdr. rounds ordered in Canada in the previous month.[3] No direct cordite orders were placed in the Dominion until 31 March, 1916, on account of the high prices asked and uncertainty as to the capabilities of the firm and the quality of the raw material available.[4] The Imperial Munitions Board then arranged the delivery of cordite from Canada to England in exchange for cordite and nitrocellulose powder to be provided from the United States for the 18-pdr. ammunition.[5]

The United States were the chief source from which propulsive explosives could be imported, and large factories existed both for cordite and nitrocellulose powder. The most important of these were the Hercules Powder Company and the du Pont de Nemours Company, originally components of the du Pont Company which had been dissolved under the Sherman Law shortly before the war, the double-base brands of propellants being then assigned to the Hercules Powder Company, and the single-base explosives (nitrocellulose powders) to the du Pont de Nemours Co. In October, 1914, negotiations were begun through a British firm (Nobel's) for the purchase of 2,000,000 lb. of nitrocellulose powder from the latter company, delivery to begin in April, 1915. With one exception, all other explosives were purchased in the United States through the authorised agents of the British Government (Messrs. Morgan).[6] In January, 1915, this firm was instructed to take active steps to buy American nitrocellulose powders for the War Office in order to release more service cordite for naval use.[7] At the time, it was impossible to obtain immediate deliveries from du Pont, since the firm was already subject to enormous pressure from foreign governments, from contractors for the Allies, and from the American firms contracting for complete rounds of ammunition. The additional capacity laid down by du Pont de Nemours was already absorbed by Russian and French orders by 21 January, 1915. Accordingly, it was only possible to negotiate the new nitrocellulose powder contracts, which involved extensions to plant, for delivery late in the year.[8] The first purchase of cordite from the Hercules Powder Company was also negotiated during January, 1915, earlier delivery being secured in this case.[9]

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1 HIST. REC./R/1143/8, No. 17; see Vol. II., Pt. VI., pp. 2, 19.

2 HIST. REC./R/1142/8.

3 94/Gen./226; cf. *Royal Commission on Shell Contracts, Minutes of Evidence*, i., 31.

4 On C.P. 101881/14.

5 95/C/108.

6 Contracts/P/2067.

7 Contracts/N/588; see above, p. 2.

8 Contracts/N/593.

9 Contracts/P/2067.

During March, 1915, it became clear that the capacity of American makers for the following year was rapidly becoming absorbed. Orders were therefore placed in April, 1915, both with the du Pont and Hercules Powder Companies for deliveries to be made during the first six months of 1916. By 10 May, it was calculated that no further orders need be placed in America for 1916 supplies, since the total requirement for the army during that year stood at 32,000 tons against an anticipated supply of 34,000 tons from all sources.[1] Eventually, however, the purchase of propellants from overseas was continued and formed about 50 per cent. of the supplies throughout the war in spite of the obvious disadvantages of so great a reliance upon an outside source. There were several additional drawbacks to this course in 1915. American prices excluded the cost of transport and were very high as compared with British rates. Although no capital advances by the Government were involved, as in the case of home contractors, yet the advance of a very large proportion of the contract price was claimed by the American firms, who received in one instance 25 per cent. of the whole sum in advance, and in another were paid 80 per cent. on each lot as it was brought to the drying stage.

The arrangements made for standardising American explosives with British service cordite have been described above.[2] The methods of manufacture were laid down in the contract terms. Inspection by representatives of the War Office took place at works and during production. The explosive was proved at the companies' ranges or at Bethlehem under the inspecting officer sent out by Chief Inspector, Woolwich.[3]

VII. Project for the Home-Manufacture of Substitutes.

The purchase of substitute explosives from abroad was followed by a scheme for their manufacture at home. In April, 1915, the War Office was about to undertake responsibility for supplying acetone to the trade as well as for Government factories for the year 1916. Inquiries as to the American market had shown that this material was likely to be a limiting factor in the expansion of home capacity for cordite production.[4] Investigations as to the propellant position for both services made by Mr. A. J. Balfour and by the Munitions of War Committee showed a very considerable deficit in the naval supplies.[5] The arrangements made for military propellants by 10 May, 1915, sufficed to meet prospective requirements for filling in 1916 with a margin of 2,000 tons, unless the deliveries of shell were largely increased.[6] A more immediate difficulty lay in the considerable deficit between the needs of the Admiralty and the supply of naval cordite arranged for the latter half of the year 1915, until reliance could be placed upon the full output from the Royal Naval Cordite Factory and the trade extensions initiated by the Admiralty.

[1] 94/C/194.
[2] See above, p. 2.
[3] Contracts/P/2067, N/524, 534.
[4] HIST. REC./R/245/1; see Vol. VII., Pt. IV.
[5] C.P. 27289/15; HIST. REC./R/172/9.
[6] 94/C/194.

Since alternative explosives could be used on land but not by the navy, the Munitions of War Committee proposed on 13 May, 1915, that a largely increased supply of some substitute should be provided for the army in order to release more service cordite for the navy. The Committee invited Lord Moulton to find a means of supplying a maximum quantity of 2,000 tons of such a substitute monthly.[1] He reported on 27 May, 1915, that he had investigated certain sites suitable for a single factory of the enormous dimensions required. He also recommended that the new works should be laid down for the newly evolved cordite R.D.B., rather than for nitrocellulose powder since the design of the plant and the methods of manufacture would follow lines well known in this country, while the alternative nitrocellulose powders were less stable and more difficult to dry.[2] During the month of June preparations were made for the new factory, for which a site was eventually found at Gretna towards the end of the month.[3]

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[1] HIST. REC./R/172/1. (Mr. Wolfe to Lord Moulton, 13.5.15).

[2] HIST. REC./R/172/7 ; 263.5/5.

[3] Enclosure to Gretna 2891, No. 1, ff 1-57.

CHAPTER VII.

PROPULSIVE EXPLOSIVES: THE EXPANSION OF SUPPLY FOR THE ARMY (JUNE, 1915—JULY, 1917).

The projects described above for uniting control over the supply of propulsive explosives for both services were finally abandoned when Mr. Churchill left the Admiralty in May, 1915.[1] Arrangements were then made to render the navy independent of the production of guncotton at the Queen's Ferry factory. On 21 June, 1915, it was agreed verbally between Mr. Balfour and Lord Kitchener that the whole output from Queen's Ferry should be allocated to the land service.[2] A week later, further trade extensions were sanctioned by the First Lord as a margin over the programme for naval cordite in 1916. Shortly afterwards an agreement was reached as to the allocation of the trade factories between the two services.[3]

The two chapters which follow deal only with the action taken by the Minister of Munitions in regard to the supply of propulsive explosives for the land service.

I. Effects of the First Ministry Programme.

(*a*) Schemes for the Home Production of R.D.B.

The first steps taken under the Ministry of Munitions were the completion of the guncotton factory at Queen's Ferry and the organisation of R.D.B. manufacture within the United Kingdom. On 26 June, 1915, the Minister (Mr. Lloyd George) authorised Lord Moulton to build the new national factory for producing cordite R.D.B.[4] The site was subsequently fixed at Gretna in order to facilitate the use of Queen's Ferry guncotton for one-half of the cordite.[5] Mr. Lloyd George also gave instructions that arrangements should be made with British cordite makers to change over to cordite R.D.B., the State bearing the cost of any necessary additions to plant or equipment to prevent any appreciable reduction in output by reason of the change.[6]

Negotiations began on 8 July, 1915, with Nobel's for the erection at State cost of a large propellant factory for propulsive explosives in the neighbourhood of their T.N.T. plant at Pembrey. On 28 September, the firm agreed to construct this plant for a maximum weekly output of 150 tons of R.D.B. in addition to lesser quantities of ballistite and

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[1] See above, p. 29.

[2] Hist. Rec./R/1122.7/5; G.02585.

[3] See above, pp. 92, 96.

[4] Enclosure to Gretna, 2891, f. 51.

[5] Major Corbett Unregistered Memorandum (12/7/15).

[6] Enclosure to Gretna, 2891, f. 51.

rifle cordite.[1] Towards the end of October, 1915, it was arranged that both the propellant and the T.N.T. units on this site should be nationalised as from 1 January, 1917.[2] From 5 July, 1915, until the end of the year, the military cordite makers carried out full scale experiments with a view to taking up the production of R.D.B., pooling their experience at conferences summoned by Lord Moulton. The practical difficulties of the new method of manufacture were thus overcome by the beginning of December, 1915.[3]

(b) PURCHASES OF AMERICAN EXPLOSIVES.

Further purchases of overseas supplies became necessary in September, 1915, in order to provide for the maximum gun ammunition programme for 1916, as then projected by the Minister.[4] The decision taken in May, 1915, against placing further orders in America had been generally followed until this month. Offers of nitrocellulose powder made during June, July and August were for the most part refused; but purchases were made on behalf of the Russian Government in July, and a reserve of 14,500 tons of this explosive was accepted in August for delivery between September, 1915, and December, 1916.[5] Again, an order was given in July, 1915, for cordite, which the Hercules Powder Company proposed to manufacture from acetone obtained by a method other than the destructive distillation of wood. The same contract provided also for the purchase of acetone similarly made. Very considerable delays occurred with the new plant and process, and the attitude of the company's sub-contractors added to these difficulties. This source of acetone supply was accordingly abandoned in August, 1917.[6] Nevertheless, a later contract was placed with the Hercules Powder Company in December, 1916, for deliveries during the following spring of cordite to be made from acetone not obtained by wood distillation.[7]

Towards the end of September, 1915, the Minister decided to make further purchases in America in order to meet a slight deficiency anticipated on the original 1916 shell programme and a still heavier deficiency on the basis of the maximum programme for 1917. The former had involved the supply of 67,000 tons of propulsive explosives during the year 1916; whereas the deliveries expected amounted to about 52,000 tons, of which some 24,000 were to come from America, 15,000 from British contractors and 12,000 from the national factories, *i.e.*, Waltham Abbey and Gretna. The output in view for 1917 was 97,500 tons against a probable requirement of 122,000 tons. Thus the apparent deficit on the two programmes was 39,500 tons; but this had been calculated on a basis which allowed for a 35 per cent. deficit on deliveries, and for an empty shell programme allowing 33 per cent. margin on heavy, and 60 per cent. on light shells in 1916. Upon negotiation, it was found that du Pont's would offer a total

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[1] X/236/89; HIST. REC./R/1122.7/12.

[2] See above, p. 56.

[3] See above, p. 3.

[4] 95/Firms D/13.

[5] 95/Firms D/2.

[6] 95/Firms H/3; 95/A/563.

[7] 95/C/253.

of 50,000 tons at rates which amounted in all to £18,000,000. It was considered that a further purchase of 20,000 tons of American explosive would amply meet the British requirements for 1916 and on 5 November, 1915, an order was placed with du Pont's for 36,000 tons of nitrocellulose to be delivered during 1916, 19,000 tons being for British service and the rest for France and Russia.[1]

II.—Increased Dependence on Overseas Supplies.

The decision taken in September, 1915, to make further purchases of American propulsive explosives marked a further step in the rapid growth of the army's dependence upon overseas supplies. The first step had been taken when the purchase of cordite was negotiated with the Hercules Powder Company, in October, 1914, for delivery in the following April.[2] The acceptance of nitrocellulose powders for the use of the army in March, 1915, had opened up a still larger source of overseas supply.[3] Actual deliveries from overseas had amounted to 3,200 tons by the end of September, 1915. The total amount of nitrocellulose powder and cordite imported during the whole of the year 1915 was 13,500 tons, or rather more than the home production for army purposes (11,250 tons). During 1916 overseas supplies far outpassed those from home, the one standing at 70,000 tons, the other at 22,000. It was not until the following year (1917) that the steps taken to organise home production of cordite R.D.B. bore their full fruit in an output of 93,000 tons. Even so, the gun ammunition programme which had been formulated in the previous July could only be met by large purchases from Canada and the United States.[4] While overseas deliveries of cordite in this year were maintained at about the same level as in 1916, the purchases of American nitrocellulose powder reached their zenith during 1917, outpassing the year's home production of propellants by 12,000 tons. The reasons for maintaining this dependence upon imported propellants are related below.[5]

(a) Canadian Contracts.

Canadian deliveries to this country were organised from the spring of 1916 onwards. No direct orders had been placed with the one established explosives firm in the Dominion (Canadian Explosives, Ltd.), until the agreement of March, 1916, whereby the cordite ordered for complete 18-pdr. rounds of Canadian shell was sent to England and replaced by explosive from the United States.[6] The change was made in order to increase the output of the sizes then most wanted, the firm undertaking to supply those above size 8, while it was a definite policy to limit orders in the United States to the smaller sizes,[7] in which the danger from instability would be considerably less.[8] In August, 1916, the cordite output of the company was increased by means of improved methods of acetone recovery and the surplus production was accepted at a

[1] 95/Firms D/13.
[2] See above, p. 97.
[3] See above, p. 2.
[4] 95/90.
[5] See below, p. 114.
[6] See above, p. 97.
[7] 95/C/108.
[8] Contracts/N/524.

reduced price.[1] A further order, extending over the first six months of 1917 was placed with the firm in October, 1916.[2] Finally, in July, 1917, when the quantities of complete 18-pdr. ammunition to be delivered from Canada were greatly reduced, arrangements were made to take from the company's private factories only the deliveries then due on its current contracts.[3] No further orders were placed with the firm during the war; but certain stocks were purchased from them early in 1918.[4]

(b) DEVELOPMENT OF STATE MANUFACTURE IN CANADA.

In December, 1916, the same company agreed to erect and operate at Nobel, under the direction of the Imperial Munitions Board, the first State factory for cordite manufacture in Canada. The company received a lump sum payment as commission on the construction of the plant, and advanced the money for this purpose without interest, it being refunded on monthly progress certificates. The site and factory became the property of the British Government. The works were operated at a fixed commission upon each pound of cordite produced.[5]

A national factory for the production of nitrocellulose powder in Canada had already been arranged in November, 1916, when the O'Brien Company agreed to operate under the Imperial Munitions Board certain works at Renfrew, Ontario, which in the first instance had been subsidised by the Canadian Government as a source of supply for the powder needed for complete shrapnel rounds. The nitrocotton for these works, which were operated as "British Explosives, Ltd.," was originally obtained from the United States. The Imperial Munitions Board subsequently arranged with another company (the Davis Durkin Corporation) to erect and operate nitrocotton plant at Trenton, Ontario, in order to serve the Renfrew factory.[6] This scheme was sanctioned in November, 1916, and in the following December decision was taken to duplicate the nitrocotton plant and also to erect new nitrocellulose powder plant at Trenton in order to develop Canadian production still further. The Trenton factories were operated by the British Chemical Company, Ltd., at a fixed commission per pound produced. Deliveries from Renfrew began early in 1917, from the Trenton factory in the following August.[7] It was expected (in May, 1917) that the national cordite plant for 900 tons monthly and the national nitrocellulose powder plant for 1,260 tons monthly would reach their full output by the end of the year.[8]

(c) INCREASED IMPORTATION OF NITROCELLULOSE POWDER FROM U.S.A.

In the first instance, it had been considered that the American orders placed in 1915 would cover the supplies required from this source during 1916, and offers for delivery within the year were rejected in April, 1916. Negotiations to meet the 1917 programme were then

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[1] 95/C/108.
[2] 95/C/257.
[3] 95/C/435.
[4] 95/C/257; 95/C/528.
[5] 95/C/276.
[6] 95/N/28.
[7] 95/N/43.
[8] 95/134.

renewed, one of the main difficulties in coming to terms with the American makers being their insistence upon payment in advance. On 15 June, 1916, the British agents informed the Minister that du Pont's were willing to hold their entire capacity for the benefit of the British Government and the Allies, provided they received firm orders for a minimum of 20,000 tons, delivery to begin in September, 1916. It was also reported that the firm might be ready to accept some form of interest-bearing security in part payment. At the time, the Russian Government expected to purchase 15,000 tons of nitrocellulose powder and the Minister of Munitions was prepared to take the balance in order to guard against shortage of acetone or possible failures in the output of cordite R.D.B. On 13 July, 1916, he conferred with Russian, French and Italian delegates and emphasised the advantages arising from joint purchases of large quantities. The British Government was already negotiating on behalf of the Russian and Italian Governments, and the French delegate (M. Thomas) agreed that an order should be similarly placed on behalf of his Government. Independent negotiations for all the French requirements in America were, however, already far advanced, and a separate French order was placed before the agreement of 13 July was put into effect. Eventually, an order for 29,000 tons of nitrocellulose powder was closed with du Pont's by the British agent about 9 September, 1916, certain quantities being allocated to Russia and provision being made for the future transfer of a portion of the British allocation to the Italian Government. Great Britain eventually took 15,150 tons, and Russia 12,500 tons out of the 29,000, while the remaining quantities were allocated to Belgium and Italy. A contract for nitrocellulose powder was also placed with the Hercules Powder Company in August, 1916, on behalf of the Russian Government.

In October and November, 1916, the Ministry was faced with the prospect of a serious shortage of propulsive explosives, due to the enormously increased gun ammunition programme for 1917, and to the need for providing against considerable losses at sea. The situation was met partly by a reorganisation of home supplies,[1] partly by the purchase of further quantities of nitrocellulose powder from abroad. Attempts were made to spread the basis of overseas supply by placing orders with the Aetna Powder Company for nitrocellulose powder produced in Canada, and in the United States[2]; but, owing to financial embarrassments, the firm ceased to operate either of its plants about February, 1917, and the total deliveries made were considerably less than half the orders placed.[3] Another 3,000 tons of nitrocellulose powder was also obtained from the Hercules Powder Company and issued to the Russian Government.

The surplus output from du Pont's nitrocellulose powder works during the first six months of 1917 was purchased in December, 1916, in accordance with a recommendation from the Inter-Allied Munitions Bureau, with the intention of meeting a considerable deficit on the total requirements of the Allies.[4] At this time, the financial position in

[1] See below, p. 110.
[2] 95/N/22; 95/N/35.
[3] 95/N/22.
[4] 95/N/17.

regard to purchase of munitions in the United States was becoming exceedingly serious. Further negotiations on behalf of the Allies were suspended by reason of Treasury rulings limiting the quantities of nitrocellulose powder to be allocated to Russia and prohibiting any allocation to Rumania. The French Government was accordingly advised to make independent provision for its own needs while Great Britain was left with orders considerably above her own requirements until February, 1917, when Treasury sanction was given for the allocation of over 9,000 tons from du Pont's to the Russian Government. In March, 1917, options for 42,000 tons of nitrocellulose powder from du Pont and 4,000 tons from the Hercules Powder Company were exercised in order to provide a margin over the British requirements in 1917, to meet increased demands for this powder for 18-pdr. and other ammunition and to cover the defaults from the Aetna Powder Company.[1] No further purchases were made until it became necessary to provide for the new gun ammunition programme. About 18 June, 1917, the British agent, at a conference at which Lord Northcliffe and Sir Hardman Lever were present, closed with du Pont for certain deliveries of nitrocellulose powder from November, 1917, to June, 1918. Purchases were made by the French Government at the same conference through the members of the French Mission to America, and further quantities were bought by the British Government in the following month. Upon both of these contracts the firm insisted at first upon an immediate advance of 25 per cent., although delivery was not due to begin for some months. Eventually they accepted payment of this proportion in cash spread over the four months, July to October, 1917.[2] Deliveries on these orders for 1918 were subsequently spread over a longer period to meet restrictions in the programme which will be considered later.[3] Supplies of cordite from the United States were abandoned entirely in the summer of 1917, and beyond the acceptance of an over-run no further orders were placed with the Hercules Powder Company for this explosive, which was more costly than nitrocellulose powder and involved the consumption of acetone.

III.—The Development of Home Production.

(*a*) CONSTRUCTION OF THE NATIONAL R.D.B. FACTORIES.

The creation of the vast cordite factory at Gretna of necessity occupied many months. It was completely self-contained in regard to the supply of acids and the refining of glycerine. It was laid out for every stage in the process of making finished cordite from cotton waste and acids, except that one-half of the nitrocotton used was the product of the Queen's Ferry factory. The growth of the factory[4] and the development of the town to accommodate its workers are treated in detail elsewhere.[5]

Constructional work did not approach completion for more than a year from July, 1915, when the land was first taken. During the autumn of 1915, a sub-division of the works was under discussion with a view

[1] 95/101.
[2] 95/N/66.
[3] See below, pp. 113-114.
[4] See Vol. VIII., Pt. II.
[5] See Vol. V., Pt. V.

to lessening the difficulty of moving over 10,000 employees to a new locality and on the ground that the danger risks would thus be dispersed. Decentralisation was also advocated by Sir Charles Harris as a means of diminishing the expenditure on housing. The supply department eventually persisted in their original project for building the whole factory in the single area which centred round Gretna and extended from Longtown to Dornock. It was considered that this centralisation would concentrate technical and administrative control, would avoid the re-duplication of labour and expenditure on power, lighting and railways, and would obviate the danger and cost of hauling the paste from factory to factory. It was maintained that a proper regard to safety conditions, particularly the spacing of the buildings, would prevent any increase in the risk as a result of the size of the factory.[1] It was not until January, 1916, that it was finally decided that the new factory should produce cordite R.D.B., which had then been satisfactorily manufactured on a works scale by the trade.[2] Two of the cordite ranges started production from paste supplied by Nobel's on 28 June, 1916, and from Gretna paste on 22 August following. The last of the ranges began output on 10 September, 1917. In the interval all the other sections of the factory had been gradually brought into full operation. The output thus rose from 20 tons weekly at the end of September, 1916, to the full 800 tons for which the factory had been built. This was attained by a record week's work in June, 1917, more than two months before the last ranges came into operation.

The output of guncotton from the Queen's Ferry plant, which had started up early in December, 1915, was used for naval purposes until Gretna began production. The change over to the nitrocotton needed for R.D.B. manufacture began at Queen's Ferry in May, 1916, and was effected gradually, until in October, 1916, the whole of the plant was engaged upon nitrocotton for Gretna.[3]

The propellant side of the factory erected by Nobel's at Pembrey was producing ballistite and rifle cordite in March, 1916, and began making ordnance cordite in the following May.[4]

The extensions which had been made to the Royal Gunpowder Factory at Waltham brought its weekly output up to 140 tons of cordite M.D. by September, 1915. Beyond this, any considerable expansion was hampered by local conditions. The gradual development of the cordite works along a narrow strip of land had resulted in a lay-out which compared unfavourably with that of a modern factory, such as Gretna, planned and built as a complete whole. Without the acquisition of new land, any further expansion would only have increased the disadvantages of the lay-out. The water supply was insufficient even to provide power for the original gunpowder mills, although the works lay so low that floods seriously delayed the constructional work during the winter of 1914-15.[5] Accordingly, from

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[1] Sir Sothern Holland to Dr. Addison (30/9/15). Sir H. Llewellyn Smith's Papers D.M.R.S. 212.

[2] 95/1/372. [3] 95/2/200. [4] Hist. Rec./H/1122.7/6.

[5] Hist. Rec./R/1122.12/1 ; 1122.7/26.

September, 1915, onwards, the chief developments in the Royal Gunpowder Factory were restricted to the installation of plant for 50 tons of rifle cordite weekly, which was arranged in January, 1916. Upon the subsequent decision to use nitrocellulose powder for small arms ammunition this unit was utilised for ordnance cordite. Minor extensions were also intended to balance the output of the various units. By this means, the weekly capacity was brought up to 200 tons of cordite M.D. It was not until the end of 1916 that the factory changed to cordite R.D.B. for the purpose of economising acetone. The output then rose to 250 tons weekly. It was not practicable to make the factory completely self-contained by adding certain units such as oleum plant or glycerine refineries; but certain re-arrangements were effected in order to facilitate costing.

(b) RELATIONS WITH THE TRADE.

The eight cordite makers, called into conference in June, 1915, as to the practicability of changing over to the manufacture of cordite R.D.B., expressed considerable unwillingness to alter their fixed methods of manufacture,[1] but agreed to carry out small-scale experiments. By the end of August, 1915, they had made the new explosive with success, but reported considerable practical difficulties due to the stickiness of the cords. During November, the Explosives Supply Department undertook to assist contractors by obtaining from France details concerning plant for making and recovering ether-alcohol. The practical difficulties of initial manufacture were overcome by 1 December, when three of the firms undertook to make the new form of cordite.[2] Cordite R.D.B. manufacture was then gradually introduced by most of the firms making for the army, and also at the national factories at Gretna, Pembrey and Waltham Abbey.[3]

The principle that the State should bear the cost of constructional work for the change-over to cordite R.D.B. had already been applied to the cordite makers, when the Admiralty and the War Office had agreed to subsidise their extensions in the autumn of 1914.[4] One or two contracts were placed shortly after the outbreak of war at prices enormously enhanced over peace rates to cover capital expenditure on extensions. When the departments agreed to subsidise further extensions, the prices payable, though less than those where the firm bore the whole capital expenditure, still included charges representing the proportion borne by the firms.[5] In April, 1915, the desirability of limiting the profits of the explosives firms as well as of the armament firms was raised, in view of the difference between the rates charged for T.N.T. by Nobel's and the estimated cost of manufacture.[6] Early in July, 1915, the cordite makers were informed that the Minister of Munitions proposed to declare their factories controlled establishments under the Munitions of War Act. Seven out of the eight firms protested that it was not the intention of the

[1] 74/6/3658.
[2] S.R. 14373/43.
[3] HIST. REC./H/1530/1, p. 68.
[4] See above, p. 93.
[5] HIST. REC./H/1530/5, pp. 13-14.
[6] 94/T/49; see above, p. 56.

Act that the powers of control conferred in its second part should apply to industries, such as their own, where output would not be affected by the relaxation of trade union regulations. They maintained that no difficulty had been experienced in recruiting the unskilled labour from which they drew and trained their own workers, and that no labour troubles had been experienced or were anticipated. Finally, they maintained that makers of explosives should have special consideration in view of the exceptional nature of their business. A similar attitude was adopted by the Admiralty advisers who maintained that there were no known trade union rules or practices which restricted output or employment in the explosive industry; that the Explosives Act, 1875, already provided for the regulation of work as amply as would be possible under Section 4 (5) of the Act; and that it was undesirable to employ War Munition Volunteers in an industry which drew unskilled labour through the labour exchanges. The crux of the position thus lay in the control of profits, and it was not until March, 1916, that the cordite makers, including contractors to the Admiralty, became controlled firms.

Whatever justification there may have been for the prices agreed in 1914 and 1915, it was felt that they afforded too high a margin of profit as time went on and firms were called upon to continue to produce at full capacity. Early in 1916, negotiations were entered into with the four cordite makers working for the Ministry with a view to revising prices. After very protracted negotiations, considerably reduced prices, operative to 31 December, 1916, were agreed with three firms, and a special arrangement was made to meet the particular conditions of a fourth (Kynoch, Ltd.). Under this scheme the Ministry bore the total capital expenditure incurred on cordite plants since the beginning of the war, less an agreed post-war value, and allowed the firm a fixed profit over cost up to 31 March, 1917, after which it was required to quote on an analysed cost sheet. All these reductions were in part consideration of the arrangements made for indemnifications against loss and damage by fire or explosion, which have already been described.[1]

With a view to fixing prices to cover the year 1917, the firms were instructed to quote on an analysed cost of production sheet, basing their calculations on fixed prices for the main raw materials, viz., cotton-waste, glycerine, nitrate of soda, oleum and solvents, which the Department undertook to make available at these rates. The Department was by this time prepared to indemnify contractors against loss by fire and explosion, and as they all accepted this condition, danger risks were eliminated from the cost analysis. All the firms asked for a sliding scale in respect of wages, since increases were subject to the approval of the Ministry, and for protection in the event of the Ministry's raising the prices fixed for raw materials. Sliding scales dependent on these two factors were accordingly introduced. The prices finally agreed were all below those at first asked, and varied slightly to meet the circumstances of individual firms.

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[1] See above, p. 79.

They represented a very considerable all round reduction on the rates of 1915 and were even slightly lower than the latest pre-war contract prices, although wages had risen by at least 50 per cent. and the prices fixed for raw materials represented an advance of 4·2d. per lb. of cordite made.

The procedure adopted in fixing the prices for 1917 by individual negotiation based on the cost returns of each firm was markedly successful. The rates thus arranged were a correct reflection of the actual cost of production in each case, ceasing to approximate, as they had before the war, to a level which doubtless represented a very good margin of profit over the cost of the dearest production. These results were mainly attained by fixing prices for raw materials, by allowing a sliding scale for wages, and by bearing fire and explosion risks, that is, by eliminating the main trading risks, to cover which an ample margin of profit had been allowed under normal conditions. The supervision exercised by the branch over the consumption of raw materials and the information and assistance afforded by it on technical details of manufacture, also contributed to reduce the cost of production. The only firm to which the new system was not then applied was supplying cordite to the Admiralty alone.[1]

With the special object of making as great an increase as possible in the home supplies of cordite with the minimum of expenditure on new plant, a systematic investigation was made in the latter half of 1916 into the capacity of all the propulsive explosives factories. The whole process of manufacture in each factory was divided into suitable units, and the plant capacity of each unit calculated in terms of the finished explosive. The results obtained were expressed in a series of charts. A study of these charts showed that many of the factories were badly balanced, and in most cases it was found that by strengthening weak units a large increase in output could be obtained for a comparatively small expenditure of capital. Arrangements were therefore made with the contractors for the extensions thus indicated, the cost involved being borne by the Ministry.

Technical control over the government and trade factories was effected by regular visits of inspection from the staff of a supervisor of factories who was appointed to the Propellants Branch in April, 1916.[2] Experiments carried out by one contractor (Nobel's) enabled the trade as a whole to recover the solvent in cordite R.D.B. manufacture with little or no alteration to their plant. Another series of experiments carried out at various factories resulted in a fall from 33 to 23 tons in the quantity of acetone used for each ton of cordite M.D. The system of testing efficiencies and costs, which was instituted in the State factories for high explosive manufacture, was applied also to the national factories for making propulsive explosives. The existence of these enormous cordite plants, particularly Gretna, which started up during the summer of 1916, gave the Department a great measure of independence in its negotiations with the trade. From June, 1917, onwards, contractors submitted detailed information

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[1] HIST. REC./H/1530/5, pp. 13-21.

[2] HIST. REC./H/1530/5, p. 22.

as to their operations, upon which, as well as upon experience gained in the State factories, was based a comprehensive scheme for the study of plant capacity, process efficiency and the costs of manufacture. The system of studying process efficiency was elaborated for the whole process of cordite manufacture. The private makers readily agreed to submit returns from their factories and made minor plant alterations to ensure their accuracy. Towards the end of 1917 the same system was extended to contractors under the Admiralty as well as to the Royal Naval Cordite Factory.

(c) Transfers of Admiralty Capacity.

By October, 1916, the Admiralty had accumulated large stocks of cordite, whereas the Ministry was endeavouring to provide for the vastly increased demands for the 1917 gun ammunition programme. It was accordingly arranged that the output of all naval contractors, save one, should be transferred to the army, and that the entire cordite production of the Royal Gunpowder Factory should be used for military purposes. This factory and Nobel's works at Ardeer changed over to R.D.B. from the beginning of 1917 in order to free as much acetone as possible for the Royal Naval Cordite Factory and the one contractor whose output was retained by the Admiralty.[1] The new allocation brought the total home production for military purposes up to 1,856 tons of cannon, and 205½ tons of rifle, cordite weekly. From the beginning of 1917 onwards, manufacture of rifle cordite was either suspended or greatly reduced in view of the decision to use nitrocellulose powder for small arms ammunition. In July and August, 1917, respectively, the output of a second and third firm was re-allocated to the Admiralty in order to accelerate production of the high grade cordite demanded for naval purposes.[2]

(d) Schemes for the Home Production of Nitrocellulose Powder.

The increased output obtained by balancing plant during the latter half of 1916, and by the allocations of naval capacity to the army in November, 1916, were not in themselves sufficient to meet the needs of the 1917 gun ammunition programme. Increased overseas purchases were under negotiation; but the Lords of the Treasury represented to the Minister on 24 November, 1916, the gravity of the financial situation arising out of the large purchases of munitions in the United States. They urged the importance of obtaining increased supplies from existing or new factories in the United Kingdom.[3] An effort was therefore made to meet the situation so far as propulsive explosives were concerned by establishing within the United Kingdom factories for nitrocellulose powder.

[1] 95/C/251, 95/C/314. [2] 95/C/314. [3] 95/N/17.

Until this time, no home-produced nitrocellulose powder had been purchased by the British Government. Small quantities had been made for foreign States by at least one of the cordite makers (Nobel's). Another firm (Curtis's and Harvey) had adapted their smokeless sporting powder plant to make Belgian nitrocellulose ribbon propellant in October, 1914, and had erected a new factory to supply the Belgian Government with this explosive, April to July, 1915. Three schemes for the home production of nitrocellulose powder for the British army were set on foot in November, 1916. The one was for a national factory to produce 1,000 tons weekly under direct control from headquarters. This scheme was sanctioned by the Minister on 31 October, 1916, and a suitable site was found at Henbury, near Bristol, by the end of December, by which time also a mission to France had reported on methods of production there. As a result of this report it was decided on 1 January, 1917, to use the American, rather than the French, process. The other two schemes were for agency factories, the one to be erected and operated by Nobel's, for 150 tons of powder weekly, the other by a second firm for 100 tons weekly. The former materialised as H.M. Factory, Irvine; the latter was definitely abandoned in February, 1917.

The first construction work began at Henbury in the last week of 1916; building operations began at Irvine in January, 1917. On 6 April, 1917, war was declared upon Germany by the United States and the position in respect to making nitrocellulose powder was immediately changed. Four tons of imported raw materials were needed for every ton of nitrocellulose powder made. If the finished explosive could be made in America, the transport of cotton and sulphur was eliminated and shipments of Chilian nitrate of soda followed shorter and safer routes. The actual difference in tonnage between importing 500 tons of finished explosive weekly from an American west coast port and making it in Great Britain was between 800 and 1,200 tons a week, quite apart from the materials needed for constructing the new factories. Accordingly, the proposed Henbury factory was reduced by half on 11 April, 1917, and its construction was entirely abandoned on 16 May following, in view of the alliance with America and the increased stringency of the shipping position. The construction of H.M. Factory, Irvine, proceeded slowly under low priority. In June, 1917, du Pont's agreed that the British Government should make their improved form of nitrocellulose rifle powder free of royalty so long as existing conditions were maintained. Work began at H.M. Factory, Irvine, in February, 1918, with the reconditioning of damaged American powder. Ordinary service production began in April, 1918, and rather more than 1,000 tons of explosive had been completed when the factory was instructed to cease operations on 13 November, 1918.[1]

[1] HIST. REC./R/1530/11.

III. Cost of the National Factories for Propulsive Explosives.

The completion of the factory for nitrocellulose powder at Irvine brought to an end the construction of national factories for propulsive explosives. The capital expenditure on the largest of these, Gretna, was over £9,000,000, a sum which included the cost of creating the new town. The expenditure on the new national establishments for the manufacture of cordite and nitrocellulose powder between the outbreak of war and 31 March, 1919, was £10,302,828;[1] but this excludes the cost of the joint factory for propulsive and high explosives at Pembrey, on which the total expenditure was £2,850,591. Neither does it include the sums expended upon plant for the production of materials, such as guncotton, other than the units established in the explosives factories themselves.

The ultimate cost of the abortive Henbury scheme was reduced to £154,382 by two liquidation committees working locally and at headquarters. By keeping in close touch with other departments in disposing of plant and material and by restricting compensation to payment for work actually done, they liquidated expenditure and commitments which had amounted in May, 1916, to £3,585,000.[2]

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[1] This total was made up as follows :—

Gretna	£9,295,213
Henbury	154,382
Irvine	953,233
Total	£10,302,828

[2] 95/8/296.

CHAPTER VIII.

PROPULSIVE EXPLOSIVES: VARIATIONS IN DEMAND AND SUPPLY (AUGUST, 1917–NOVEMBER, 1918.)

During the first two years of war, supplies of propulsive explosives had been well ahead of shell production. The continuous increase needed to meet the expanding gun ammunition programmes had been amply maintained in spite of the shortage threatened in the autumn of 1916. This result had been attained by transfers of naval capacity, by improvements in trade output, by large and steady production on the part of the national factories and by continued purchases of about 50 per cent. of the total supplies from America. During 1917, the stocks in hand accumulated steadily, rising from 15,000 tons at the beginning of the year to 35,500 tons in mid-August.[1] From August, 1917, until the close of the war, the problem of supply was mainly concerned with the closer balancing of deliveries and requirements and with re-allocations of orders to meet the shifting conditions of shipping and of the raw material position generally.

I. Restrictions in Output (September, 1917–May, 1918).

In September, 1917, decision was taken to fix a limit for the continuous accumulation of reserves and to leave only a six weeks' stock in hand by mid-November, 1918. For this purpose, the output from the largest State factories, Gretna and Pembrey, was restricted to 700 tons and 250 tons a week respectively, and arrangements were made with du Pont's to spread the deliveries under their contracts of June, 1917, postponing final delivery until October, 1918. It was thus anticipated that the stock on 15 November, 1918, would be equivalent to an eight weeks' supply.[2] Considerable trade capacity for the production of cordite in Canada still remained idle; while the total plant existing in the United States was insufficient to meet the requirements of the American forces in addition to the orders already placed by the Allies. The financial position did not then allow of any extension of British orders in Canada, although the United States Government was anxious that, so far as possible, British supplies should be obtained from Canada in order to set the plant in the United States free to make for the American armies.

The reduction in the tonnage allocated to the importation of iron ore in December, 1917, resulted in a revision of the gun ammunition programme for 1918, and a consequent decrease in the demand for propulsive explosives by almost one-half.[3] Under the new conditions, existing arrangements would have left 47 weeks' stock of cordite

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[1] *Review of Munitions Programme*, October, 1917, p. 19.

[2] 95/153.

[3] Hist. Rec./H/1300/16, p. 39.

and 21 weeks' stock of nitrocellulose powder by the end of 1918. The restriction of output to meet these new conditions fell on home producers rather than upon overseas contractors, both because the proportion of tonnage needed for materials was considerably greater than that for the finished explosive and because the home capacity for making nitrocellulose powder was limited to the one factory at Irvine.

The home production of cordite during 1918 was governed chiefly by the supplies of glycerine, a bye-product of the soap trade. Owing to the increased demand for margarine, the soap makers were likely to be very short of oil and fat. It was estimated that the amount of glycerine available would suffice only for 47·25 per cent. of the capacity of the home cordite factories as then working, and that, even so, scarcely any reserves of this material would exist for 1919. In February, 1918, arrangements were accordingly made to reduce the output of the national factories to 47 per cent., and that of the trade to 41 per cent., of their maximum weekly capacity without making any change in the quantities of nitrocellulose to be imported.[1] Some slight modifications were subsequently made in allocations to the trade, in view of the circumstances of individual firms,[2] the guiding principle being to economise materials and money so far as possible, while leaving contractors a large enough proportion of the Government requirements to prevent any acute sense of injustice or any considerable dislocation of labour.

The output of the national plants in Canada had already been reduced owing to lack of storage capacity,[3] and it was arranged, early in March, 1918, that supplies from the United States should be distributed over a still longer period, final delivery being postponed until December, 1918.[4] In spite of these reductions, the reserves of propulsive explosives continued to accumulate too rapidly and in May, 1918, an arrangement was made whereby a substantial quantity (over 19,000 tons) of nitrocellulose powder due from du Pont's contracts during the latter half of the year was transferred to the American Government, subject to an assignment of an equal quantity to the British Government in 1919, at the same price as the United States would then be paying.[5]

During the spring of 1918, the practicability of increasing still further the proportion of overseas supplies to home production was considered in detail as a means of freeing more tonnage. It was eventually decided in May, 1918, that the limit of prudent reduction had been reached in restricting home production to 50 per cent. of the country's capacity. It was also considered that the importation of a large proportion of certain materials for cordite manufacture (*e.g.*, oils and fats) would still be essential for other purposes; while the greater part of certain other materials, *e.g.*, pyrites and nitrate of soda, was required for high explosives, and the saving of shipping by importing the finished explosive was, in this case, small.[6]

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[1] 95/153. [2] M.C./1051. [3] 95/153.
[4] D.E.S. 2/15. [5] 95/215. [6] *Ibid.*

II. Revisions of the Programme of Supply (May–November, 1918).

A revision of the gun ammunition programme in May, 1918, slightly increased the quantities of propulsive explosives which would be needed during the latter half of the year and raised the proportion of cordite required. To meet these new circumstances, increased orders were placed with the trade, being allocated to the two firms whose output had suffered most under previous restrictions. Arrangements were also made to bring the production of the national factories up to the maximum later in the year. Nitrocellulose powder orders in Canada were continued in order to economise tonnage as well as to spread risks and utilise the plant margin available; but the financial position again prevented any extension of the cordite orders in the Dominion which would otherwise have been desirable in order to relieve the American Government of the need for erecting large new plants.[1]

The filling programme of August, 1918, still showed a prospective deficiency in the supplies of propulsive explosives during the last four months of the year, while the amount of nitrocellulose powder available during 1919 was not considered sufficient for the British requirements. Accordingly another increase in the home production of cordite was arranged in September, 1918, orders being divided between the national factories and the trade.[2] Early in October, the Imperial Munitions Board undertook to bring the production of the Canadian national factories up to the maximum, by raising the output of the Nobel cordite plant to 1,000 tons monthly and increasing the production at Renfrew to the limit of the nitrocotton capacity at Trenton. Shortly afterwards (16 October) the Trenton nitrocotton factory was destroyed by fire. In view of arrangements then under negotiation for supplies of nitrocellulose powder from the United States it was not rebuilt. These further purchases in the United States were under consideration both on behalf of the British Government and to meet the demands of the American filling programme; but the orders proposed had not materialised when hostilities ceased.[3]

III. Position at the Close of the War.

Deliveries of the nitrocellulose powder under the contracts which had been placed in the United States in June, 1917, had already been completed in November, 1918, with the exception of some 1,500 tons of rifle powder, which was practically ready and was eventually shipped to England about April, 1919. Some quantities of other sizes still remained in store in America and in February, 1919, it was agreed to waive any claim upon the American Government for supplies during 1919.[4] Stocks amounting to 58,000 tons of propulsive explosives remained in hand when hostilities ceased.

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[1] D.E.S. 2/57. [2] X/Propellants/232. [3] X/O.2/76. 77. [4] 95/134.

CHAPTER IX.

MISCELLANEOUS EXPLOSIVES.

I. Gunpowder.[1]

The gunpowder or "black-powder" used for military purposes contains 75 parts of saltpetre (potassium nitrate), 15 of charcoal and 10 of sulphur. Since the smokeless powder, cordite, was first produced at the Royal Gunpowder Factory in 1891, the use of black-powder as a propulsive explosive had gradually been abandoned. At the outbreak of war, it was chiefly required as a bursting charge for shrapnel shells. The capacity of the Royal Gunpowder Factory was chiefly allocated to the special powder needed for time-rings of fuses, of which 500 tons could be produced yearly. Three firms were engaged in making gunpowder for military purposes, their annual capacity being respectively 3,500 tons, 1,500 tons and 250 tons. The total output immediately available was thus 5,750 tons yearly.

This capacity sufficed until the end of 1915 when the demand was largely increased by an application for supplies for the Russian Government and by a project for filling certain defective H.E. shell with gunpowder. At the suggestion of one of the contractors, output was increased by the introduction of a modified powder, similar to a trade blasting powder, which needed one-half the milling required by the service powder. The new powder ("S.M. 1" or short-milled powder No. 1) was adopted for shrapnel bursters in March, 1916, and a similar powder of larger grain, "S.M. 2," was introduced in the following May as a bursting charge for common shells. One of the contractors increased output by changing over to the modified powder; another acquired trade blasting powder mills for the same purpose. A second blasting powder factory was also requisitioned for making S.M. 1. By these means the yearly output of gunpowder was brought up to 7,700 tons without the erection of new factories, while contract prices were reduced in view of the shorter time required for milling.

Apart from the need for sufficient milling and mixing plant, the chief problem in the supply of gunpowder was the provision of saltpetre, the bulk of which had been imported from Germany prior to the war. An alternative source of supply existed within the Empire in the natural deposits of India, which had formerly failed to compete with the cheaper German imports. Indian output rose gradually from 15,000 tons in 1914 to 26,000 tons in 1916. In the absence of competition and as a result of high freights, the prices doubled between 1914 and 1917, rising from £20 to £40, while the material became subject to much speculative dealing. Prices were then fixed by the Indian Government at £26 15s. or £28 10s., according to the degree of purity. All Indian exports were restricted to a single firm of brokers, and a system of export licences prevented sales for other purposes than munition manufacture and essential industries. At the end of 1915, the export from India of lower grade saltpetre had been prohibited, in order to

[1] Based chiefly on Hist. Rec./H/1520/13.

stimulate refining in that country. The refining plant at Waltham Abbey was extended and supplied one contractor with refined saltpetre. Other contractors had their own refineries.[1]

In the autumn of 1916 the project for filling defective H.E. shells with black-powder was abandoned as a result of certain prematures. This fact and the adoption of the short-milled powder enabled the allocation to Russia to be tripled in 1916. By the end of that year it was, however, necessary to increase output further for the 1917 programme. This was effected by the adoption of a short-milled powder in the igniters of cannon cartridges. In 1918 requirements were reduced to 3,800 tons and issues were made to certain of the Allies, notably to Italy.

II. Tetryl.

The manufacture of tetryl (tetranitromethylaniline) for the British services was restricted to the Royal Gunpowder Factory until the autumn of 1915. It was also produced commercially by two firms, viz., Nobel's and the Explosives and Chemical Products Company; but the trade tetryl did not reach the naval and military specification limits, which had been fixed extremely high in view of the instability of this explosive.[2]

Prior to August, 1914, production at Waltham Abbey was on a semi-manufacturing scale only, output being at the rate of 400 lbs. weekly. During the first year of war, the demand for tetryl in fuses and gaines fluctuated considerably and the plant was expanded piecemeal. By the beginning of September, 1915, the factory's output reached 5,000 lbs. weekly on a plant which was designed for 7,000 lbs. weekly,[3] and was to be extended to produce 10,000 lbs. weekly by January, 1916. It was not until the end of August, 1915, that the inadequacy of this capacity for meeting the new shell programme was fully realised. The demands for the different services were estimated in September, 1915, as between 8,000 lbs. and 15,000 lbs. weekly.[4] The exact quantities were dependent upon unsettled questions of design, such as the length of the gaine, and the explosive itself was then under suspicion as one of the possible causes of the failure of fuse No. 44.[5] Until mid-September, 1915, contractors undertaking to fill components had drawn supplies of tetryl from reserves of the Waltham Abbey product held by the Deputy Director of Ordnance Stores, Woolwich. The stocks were then exhausted and the factory's output was insufficient to fill the gaines for shell and for aircraft bombs, which were accumulating at trade factories, while the Royal Laboratory was consuming practically the whole of the output of Waltham Abbey for gaines alone.[6]

Under these circumstances, the Explosives Supply Department undertook to organise an extension of production, laying down a scheme[7] whereby the two firms familiar with this manufacture should undertake the production of crude tetryl to be purified at Waltham Abbey, the capacity of that factory should be brought up

[1] HIST. REC./H/1530/1, pp. 59-62.
[2] *Research Department Report*, 6.
[3] HIST. REC./R/1122.12/1.
[4] HIST. REC./R/1500/6.
[5] *Ordnance Board Minutes*, 15360.
[6] 74/H.E./849; 94/B/75.
[7] HIST. REC./R/1500/6.

to 20,000 lbs. weekly and other national plant for 20,000 lbs. weekly should be installed at Queen's Ferry.[1] The plant erected at Queen's Ferry was regarded chiefly as a stand-by to that at Waltham Abbey, since the production and purification of tetryl were particularly dangerous processes.[2] The nitration plant was completed by the end of February, 1916, and was used for certain experimental work only until the following October.[3] Of the two contractors, the one (Explosives and Chemical Product Company) made on an extremely simple plant crude tetryl, which was sent to Waltham Abbey for purification[4] but was rejected in considerable quantities; the other firm (Nobel's) removed existing plant from Scotland to their factory at Pembrey, which was eventually nationalised.[5] The plant at Pembrey was in operation by the end of 1915.[6] A separate unit was also erected at the Royal Naval Factory, near Poole.[7] One of the main difficulties in constructing the new plant was to procure enamelled iron nitration pots, to replace the silica vessels which had been used in small scale production but were unsuitable for manufacture in bulk.[8]

The normal method of production was by the nitration of dimethylaniline. The department undertook to supply this material to the one tetryl contractor (Explosives and Chemical Products, Ltd.) as well as to the national factories. It was obtained from a single firm (British Dyes, Ltd.), who undertook to extend their plant for the purpose, obtaining methyl alcohol from Canada.[9] Upon a reduction in the requirement for tetryl, the manufacture of this material was continued until December, 1917, when large stocks had accumulated and the contract was terminated. A part of the plant was dismantled and the firm continued to manufacture in small quantities only for the production of dyestuffs.[10]

The demand for tetryl varied considerably, mainly as a result of developments in the methods of filling and detonating shell.[11] Finally, during the year 1917 the abandonment of its use in exploders, except in shell intended for hot climates and certain large howitzers, greatly restricted the requirement for which the new capacity had been created. There were several disadvantages in its use. It was extremely costly, the expense of production averaging 10s. 6d. per lb. against 1s. 6d., the general contract price for the finely powdered T.N.T. used in exploder bags.[12] The handling of the powder was very injurious to the health of the workers; but this difficulty was partly overcome by using a corned form rather than a powder.[13] The fire risks in its manufacture and purification were particularly high. Two drying stoves were destroyed by fire at Waltham Abbey in July, 1916, the whole of a newly erected house for purification from acetone in February, 1917, and a second purification house in February, 1918.[14]

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1 Hist. Rec./R/1520/4.
2 Hist. Rec./R/1500/6.
3 Hist. Rec./H/1122.7/1.
4 X/235/161.
5 Hist. Rec./R/1122.7/12.
6 Hist. Rec./H/1122.7/6.
7 Hist. Rec./R/1122.12/2.
8 X/235/161.
9 *Ibid.*
10 X/237/21.
11 *Ordnance Committee Minutes, passim.*
12 *Ibid.*, 16047.
13 *Ibid.*, 12244.
14 Hist. Rec./H/1122.12/2.

The specification was ultimately graded into two classes in order to reduce the consumption of acetone and the cost of the explosive as a filling for fuses. Use of the highest grade, acetone-purified, tetryl was restricted to the navy and as a filling for fire channels of fuses. Tetryl purified with nitric acid was sanctioned for use in fuse-pellets and exploders. Both of these forms were graded as Class I. Class II covered water-purified tetryl for use in certain types of exploders only.[1] After the destruction of the purification houses at Waltham Abbey, the Queen's Ferry purification plants became the sole source of supply of Grade I tetryl. The production of this explosive at Pembrey and by the Explosives and Chemical Products, Ltd., was stopped with the reduction in the demand, these plants being subsequently regarded as stand-by factories.

III. Fuse Compositions.

The special black-powder for time-fuse rings was produced by certain of the gunpowder makers and by Waltham Abbey. Until August, 1915, production had only taken place in small quantities along lines which were practically experimental. The demand then increased enormously, while grave difficulties were experienced in obtaining satisfactory results, particularly with the powders needed for the new long-burning fuses. When firms were supplied by the Royal Gunpowder Factory they were prone to reject large quantities in order to safeguard themselves against failures in the completed shells or fuses for which they were under contract. Accordingly, contractors were usually left to obtain their own fuse powders from the trade. A new and successful method of manufacture was evolved and a large " blending stock " built up at Waltham Abbey.[2]

Again, the Woolwich Research Department evolved a slow burning composition (No. 202), and made it in considerable quantities for some months. Great difficulty was experienced in inducing any explosives maker to take up its production, which was particularly dangerous.[3] In August, 1917, however, a single firm contracted to supply 800 lb. weekly on special plant which was erected at government expense and remained the property of the Minister.[4] By March, 1918, the firm had overcome the grave initial difficulties in blending the materials so as to obtain a powder which would burn within the specification limits. In the meantime, the technical section of the Gun Ammunition Filling Department had undertaken exhaustive experiments with various powders, had effected certain improvements, and had introduced a standard method of blending in the filling factories.[5] The whole question of irregularities in the rate of burning in anti-aircraft fuses was also considered *de novo* by a special committee acting in connection with the Munitions Inventions Department.[6]

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[1] *Ordnance Committee Minutes*, 17528.
[2] 74/H.E./849; HIST. REC./H/1122.12/2.
[3] X/237/21.
[4] 74/H.E.C./128.
[5] HIST. REC./R/1320/10.
[6] Est. Cent. 1/281.

CHAPTER X.

SAFETY CONDITIONS IN EXPLOSIVES WORKS AND FILLING FACTORIES.

I. Position upon the Outbreak of War.

When hostilities began, the trade manufacture of nearly all explosives in service use was subject to the terms of the Explosives Act, 1875. Firms making propulsive explosives, picric acid and highly sensitive detonating agents such as tetryl or fulminate of mercury carried on their work under Home Office regulations and subject to a Home Office licence. Any factory or magazine directly controlled by a Government Department was, however, exempt from the Act.[1] Hence the Chief Superintendent of Ordnance Factories alone was responsible for the safety conditions at the Royal Laboratory, Woolwich, where high explosive shells were filled with picric acid and minor components with fulminate of mercury or tetryl, and the Superintendent of the Royal Gunpowder Factory for the safety conditions at Waltham Abbey, where cordite, black powder and tetryl were manufactured.

II. Effects of the Expansion in the Manufacture and Use of Explosives.

The manufacture of cordite remained in the hands of a few skilled firms accustomed to its production or was established in new government factories where conditions were under central control; but the regulation of high explosive production was a much graver problem. The Home Office had already experienced considerable difficulty in regulating the manufacture of nitrated coal-tar products without unduly hampering the dye industry. Picric acid had first come into use as a yellow dye and restrictions as to its manufacture had developed gradually. At the outbreak of war they were still less drastic than those applied to other explosives.[2] T.N.T. had been exempted from the provisions of the Act by order in Council in 1910,[3] as it had been considered safer than picric acid, which had to be handled under special conditions in order to prevent the formation of dangerous picrates. Practical knowledge of T.N.T. was, however, strictly limited in 1914, and official information as to its qualities was chiefly restricted to the highly pure form used in exploder bags.

The rapid expansion in high explosive production which began in October, 1914, involved manufacture under abnormal conditions. Commercial production of picric acid and T.N.T. was undertaken

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[1] 38 Vict., Ch. 17, Sec. 97.

[2] *Home Office Report on Low Moor Explosion,* C.R.V./Gen./0127.

[3] *Home Office Report of Committee on Explosions at Ardeer,* 1915.

upon converted plant in ordinary chemical works unsuited for the establishment of proper danger areas and often situated within crowded neighbourhoods. Moreover, neither the management nor the workmen had acquired the habit of mind which comes from long experience and prevents the taking of risks or breach of regulations.[1] In consequence, both the danger of explosion and the probability of serious results were increased. The construction of enormous national factories aggravated the risk of disaster arising from a single accident. Those which were intended for the manufacture of T.N.T. were built during 1915, with a view to speed and efficiency. To this end processes were employed which involved the close neighbourhood of the different operations, and buildings were concentrated without an exact regard to the distances required by the Home Office in handling other explosives.[2] Similarly, the big filling factories erected in the autumn of 1915 could not have been rendered as safe as filling factories before the war without utilising sites covering a prohibitive area. It was recognised in particular that the lay-out of the filling factory at Chilwell, planned along lines adopted in France, would result in grave disaster in case of an explosion.[3] In all these instances the urgent requirements of the forces were balanced against the strict letter of Home Office regulations. The arrangements made to secure the observance of danger building arrangements in these large new filling factories under inexperienced staff and with unskilled labour are described elsewhere.[4]

III. Relations with Local Authorities.

In several instances, contractors who made extensions for picric acid during the winter of 1914-15 experienced difficulty in procuring a Home Office licence either on account of local conditions or because of local opposition. The alternative action was for the War Department to take control of the factory under the terms of the Defence of the Realm Regulations, Clause 8. H.M. Chief Inspector of Explosives, Major A. McN. Cooper-Key, was appointed by the Army Council on 27 January, 1915, to supervise the explosive factories controlled under this clause, in order that he might be in a position to judge between the advisability of a licence under the Home Office or the assumption of control by the War Department. The control of the Chief Superintendent of Ordnance Factories over the Ordnance Factories remained unchanged by this arrangement.[5] In the following September, any possibility of delays through local obstruction was removed by Regulation 6B under the Defence of the Realm Act, which enabled the Home Secretary to license factories and magazines intended for war purposes without the assent of the local authority.

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[1] C.R.V./Gen./0127. *Seventh Report of Standing Committee on Explosions.*

[2] C.R.V./Gen./0579.

[3] C.R.V./Gen./029.

[4] Vol. X., Pt. V.

[5] 74/H.E./72.

IV. Development of Experience in regard to T.N.T. and Amatol.

Opinion as to the comparative safety of T.N.T. changed rapidly as experience was gained in its manufacture and as it was used in less pure forms than the high-grade explosive required for exploders. On 18 March, 1915, Major Cooper-Key noted that the recent behaviour of this explosive made him reluctant to assume anything with regard to its qualities.[1] The destruction of two T.N.T. factories at Penrhyn Deudraeth and Ardeer in the summer of 1915, emphasized the need for special precautions, particularly in the crystallising works. The serious extent of the damage done at Ardeer was the result of factory conditions, viz., the close grouping of numerous T.N.T. and picric acid works and large stores of T.N.T. oil in a very limited area. The Government Committee which investigated this disaster made certain recommendations as to the policing and guarding of such factories. The Committee also noted that it was desirable to repeal the order exempting T.N.T. from the Explosives Act; but, in order to avoid restriction of urgent and essential output, they recommended that the repeal should be postponed until practicable and that in the meantime special steps should be taken to improve conditions of manufacture and storage.[2]

Supervision of danger risks in the manufacture of T.N.T. thus rested with the Ministry of Munitions, whose capacity towards trade factories in this respect was purely advisory. The Department of Explosives Supply kept contractors informed as to recommendations arising out of experience gained with T.N.T. and urged their adoption so far as was possible.[3] It was subsequently alleged that the endeavours of the Ministry to ensure safety precautions at T.N.T. works were on the whole successful; but it was admitted that the officers concerned had been hampered by the absence of powers to enforce their recommendations and that the existence of the Order in Council led manufacturers to treat too lightly the serious explosive risks attached to this industry.[4] Similarly, the Home Office could only advise the new makers of T.N.T. Applicants for information were told that the exemption of T.N.T. from the Explosives Act would probably cease after the war, and that in the meantime it was desirable that its manufacture should take place in isolated buildings and under "danger building" conditions, and that the amount of material present should be limited.[5] Separate purification works were established during 1915 in the hope that a rapid adoption of other explosives would shortly reduce the need for this dangerous operation, an expectation destined to disappointment. One of the most important of these works was a converted factory owned by Messrs. Brunner, Mond, at Silvertown, a closely populated district in the East End of London. On Friday, 19 January, 1917, a fire broke out at these works and resulted in an explosion which destroyed everything in the immediate neighbourhood, set fire to oil tanks and flour mills

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[1] 74/B/456.

[2] *Report of the Committee on Explosions and Fires at Ardeer*, 1915.

[3] C.R.V./Gen./0628.

[4] 74/H.E.T./379.

[5] 74/Explosions/75.

and demolished several streets of small houses, causing very considerable loss of life. The Committee of Investigation appointed by the Home Department recommended firstly the immediate repeal of the Order exempting T.N.T. from the provisions of the Explosives Act ; secondly, certain precautions within Government controlled factories where the Act did not apply ; and thirdly, the establishment of a department of the Ministry of Munitions independent of supply departments and responsible for the safety of all Government factories making, handling or storing explosives.[1]

The Order in Council exempting T.N.T. from the provisions of the Explosives Act was repealed on 22 August, 1917.[2] In the meantime, rules for the use of T.N.T. had been issued under Defence of the Realm Regulation, 35A, by the Ministry in conference with the Secretary of State for the Home Department, and came into force on 19 February, 1917. By the time that the Order in Council was repealed, the immediate importance attaching to output from trade factories had been decreased by the reduction in the shell programme and by the completion of the large Government factories. In June, 1917, the destruction of a contractor's works at Hooley Hill, near Manchester, was attended with numerous casualties. Decision was thereupon taken to close down immediately all T.N.T. plant in congested districts. Four firms only were actually retained in the industry. Five others were closed down, but held in readiness as stand-by factories. The four firms actually manufacturing received Home Office licences, after certain alterations had been effected. Consideration of the action to be taken in respect of the five reserve factories was postponed until the question of their use should arise. The Gadbrook purification works, operated by Messrs. Brunner, Mond as a sister factory to Silvertown, were regarded as under Government control. Their safety therefore became the responsibility of the Ministry.[3] Purification of T.N.T. was also continued at H.M. Factory, Rainham, where the whole of the purification plant was destroyed in February, 1918, as a result of fire in a T.N.T. drying stove.[4]

In the following August it was proved that a fire at Messrs. Armstrong Whitworth's filling factory, Lemington Point, was due to spontaneous ignition of T.N.T. attributable to organic impurities.[5] Knowledge of danger risks inherent in presence of such impurities had developed gradually during the war. The Superintendent of Research had issued a warning against allowing contact between T.N.T. and alkalies in April, 1916,[6] and had issued a detailed report on this subject in the following June.[7] Further investigation was continued both before and after the fire at Lemington Point.[8]

When mixtures of T.N.T. and ammonium nitrate first came into use in the summer of 1915, knowledge of their properties was extremely limited, and fire was regarded as the chief source of danger.[9] These

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[1] 74/Explosions/75.
[2] *London Gazette*, 1917, p. 8691.
[3] 74/Explosions/75.
[4] C.R.V./Gen./0579.
[5] C.R.V./Gen./0602.
[6] *Ordnance Committee Minutes*, 2843.
[7] *Research Department Report*, 30.
[8] C.R.V./Gen./0602.
[9] C.R./Filling/293.

mixtures were handled only in filling factories and stores, and even the fire risk was so little realised that certain of the National Filling Factories were constructed of inflammable material. One of them, Morecambe, built mainly of wood, was entirely destroyed by fire during the first three days of October, 1917, the disaster being intensified by the presence of amatol and amatol-filled shells.[1] Continuous investigation into the properties of ammonium nitrate mixtures was being carried out by the technical officers of the supply departments and by the Committee on the Cause of Explosions.[2] An explosion which destroyed half the filling factory at Chilwell and caused very considerable loss of life in July, 1918, added nothing new to this knowledge. While the cause of the disaster was not exactly ascertained, the probability of its arising from an accident to the machinery was maintained by the Government committee which investigated the circumstances. The lay-out of the factory contributed largely to the loss of life, and so far as was possible its more dangerous features were avoided in its reconstruction. At the same time, it was recognised that it would be impracticable to render the National Filling Factories as safe as before the war without rebuilding them on enormously larger sites.[3]

V. Arrangements made by the Ministry of Munitions for ensuring Safety Conditions.

The committee appointed by the Home Secretary in August, 1915, to investigate the Ardeer explosion consisted of representatives of the various Departments concerned, viz., the Admiralty, the Department of Explosives Supply, G.H.Q., Home Defence, and the Home Office. On 2 November, 1915, the Army Council proposed the establishment of a permanent inter-departmental committee to inquire into causes of explosions at government and controlled munition factories, pointing out that both the Ministry of Munitions and the Army Council were so closely concerned that they should be represented on all such investigations.[4] Accordingly a standing Committee on the Cause of Explosions at Government Factories was formally constituted on 25 February, 1916.

Questions relating to the policing of factories were considered separately; but a representative of the branch concerned (P.M.S. 2 until May, 1917) and later a representative from the Military Intelligence Department of the War Office attended certain meetings of the standing Committee on Explosions. In October, 1917, the Special Service Branch of the Ministry became responsible for policing and acted through a Committee on the Policing of Munition Factories.

The Standing Committee on Explosions consisted of experts representing the various Departments of State as before, with the exception of the Admiralty.[5] It received notification of accidents occurring in all factories manufacturing or handling explosives,

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[1] C.R.V./Gen./0455.
[2] C.R.V./Gen./0407.
[3] C.R.V./Gen./0591; C.R./Filling/299.
[4] C.R./2059.
[5] For the personnel of this Committee see Hist. Rec./R/1122.7/16, C.R. 22059.

investigated serious occurrences and gathered information as to minor accidents, thus concentrating the knowledge gained during the war.[1] The recommendations of the committee were circulated to the firms concerned by the various responsible supply departments.

In practice, these departments regulated safety conditions in the national factories under their control and advised contractors in the light of experience gained. The management of each factory was responsible for the observance of regulations. The rules drawn up by the Explosives Supply Department for the national factories at Oldbury and Queen's Ferry were subsequently applied to other government works under the same department. Under the arrangement between the War Office and the Home Office, the Chief Inspector of Explosives continued to regulate all explosive works, whether licensed or not until May, 1916. Power was then taken under Defence of the Realm Regulation 35A. for the Admiralty, Army Council or Ministry in consultation with the Home Office to make and apply rules for the safety of all premises where explosives were made or treated, and in particular regulations prohibiting smoking or the introduction of matches. At first the new national filling factories had been subject to Home Office inspection and governed by Home Office regulations. In March, 1916, when they were about to produce on a large scale, a special consultant on danger-building practice had been appointed to assist the director of the Gun Ammunition Filling Department.[2] Shortly afterwards rules were drawn up for the national shell filling factories based on those in use at the Royal Laboratory and notice was issued that all operations were to be conducted in the spirit of danger-building work.[3] Danger building officers were attached to each national shell filling factory.[4] Of the trench warfare national filling factories, the one (Denaby) under an agency agreement was visited by Home Office inspectors; conditions at the others were regulated from headquarters. Two contractors' factories for bomb-filling were taken over in January and February on the ground of unsatisfactory conditions. These were reorganised under the direct control of the Trench Warfare Supply Department.[5]

A conference was held on 16 August, 1916, to consider as a whole the safety arrangements under the different supply departments. The restricted staff of Home Office inspectors was then insufficient to meet the increased need. It was decided that danger-building officers similar to those already employed at filling factories should be attached to all the larger national explosive factories, and that a specially qualified officer resembling the consultant on gun ammunition filling should be appointed within the Explosives Supply Department.[6] Accordingly, a Safety of Factories Branch of this department was initiated in November, 1916. The work of the branch included the inspection of all T.N.T. trade factories, which could not then be effectively inspected by the Home Department's officers by reason of

[1] HIST. REC./R/1122.7/16. [2] HIST. REC./H/1340/3.

[3] D.G.M.D./Buildings/46; for the detailed experience in the filling factories in respect to danger conditions see HIST. REC./R/1122.3/59.

[4] 74/Estab./43. [5] *Ibid.* [6] *Ibid.*

the explosive's exemption from the terms of the Act.[1] The recommendation made by the Silvertown Committee that an independent branch should be established directly responsible to the Minister for safety conditions was not accepted, since it was held that such a practice would undermine the authority of the departments. A right of direct appeal to the Minister was, however, given to safety officers in the event of any difference of opinion between themselves and their controlling supply officers.[2]

In this respect, it should be noted that in the considered opinion of certain experienced officers concerned, the special nature of the conditions affecting the manufacture of explosives on the one hand, and their handling on the other, together with the need for an intimate knowledge of the exigencies of output, were circumstances which necessitated the direct association between safety officers and the supply administration. In their opinion also, no single official could deal efficiently both with the manufacture of explosives and with their handling in filling factories.[3]

[1] 74/Estab./43. [2] 74/Explosions/75.
[3] HIST. REC./R/1122.3/59, p. 29.

CHAPTER XI.

REVIEW.

The adaptation of the workshops of a great engineering country to produce guns and shells in unprecedented numbers was a feat remarkable in itself. The organisation of the chemical industries of the country to supply corresponding quantities of explosives was perhaps a still more notable achievement, since in this respect the enemy was pre-eminent and Great Britain's resources were comparatively undeveloped.

I. Position of Explosives Supply at the Outbreak of War.

Under normal conditions, both the navy and the army looked to the Ordnance Factories and the great armament firms to provide complete rounds of ammunition, counting the explosive as a mere component part easily purchased in the open market. Cordite, which had superseded gunpowder as the standard propulsive explosive for both services, could be readily obtained from seven or eight well-known firms, whose business was maintained in times of peace by the continuous demand for sporting and blasting explosives, together with comparatively small government and foreign. orders. In addition, gunpowder and cordite were made for both services by the Royal Gunpowder Factory at Waltham Abbey. This was the only State establishment for making explosives at the outbreak of war. It was controlled by the War Department, but an agreed proportion of its output was allocated to the navy, while each department placed cordite orders with the trade independently. The factory also produced guncotton, tetryl and fuse compositions in small quantities, sufficient for the needs of both services on a peace-time basis. The guncotton was used not only for cordite production but also as a high explosive charge in torpedoes and naval mines. The only other high explosive in service use at the outbreak of war was lyddite or picric acid, a product of the dye-industry, and the standard bursting charge for high explosive shell since the South African war. Large stocks of picric acid had remained at the close of that war. In 1907 these had been taken over as a matter of convenience by the Chief Superintendent of Ordnance Factories, who obtained further supplies through the Contracts Department of the War Office as he needed them either for naval or military purposes. Small orders had been placed with the best of the picric acid makers, but a very large proportion of their works had been dismantled and the first emergency of August, 1914, proved their inability to meet the expectations of the Contracts Department, still less to provide for any resumption of filling by the armament firms. Moreover, the outbreak of war came at a time when the use of another explosive, T.N.T., was under contemplation, both as a bursting-charge for shell and also to replace guncotton for naval

purposes. The navy alone had insisted on reserving a stock of picric acid. This, with the comparatively small output of the surviving makers and the reserves which they carried, enabled the Ordnance Factories to continue filling high explosive shell from hand to mouth during the first two months of the war. The initial position in regard to propulsive explosives was more favourable. Stimulated by subsidies from the Admiralty and the War Office, the cordite-makers rapidly expanded their works to ten times their peace-time capacity during the first year of hostilities. The War Department, controlling Waltham Abbey on behalf of both services, initiated extensions of the plant there which more than quadrupled the output of cordite by August, 1915.

II. Gravity of the Position in regard to High Explosives, October, 1914.

When the demand for ammunition for the Expeditionary Force increased in October, 1914, the transference of trade capacity from the navy to the army met the immediate requirement for propulsive explosives ; but the position in regard to high explosives was extremely grave. The actual decision to change over to T.N.T. had been taken by both services in September, 1914. The demand for the new explosive had already been enormously increased by the programme for naval mines made public on 4 October, 1914. The country had practically no capacity for providing the T.N.T. to meet these two new requirements. Knowledge of the manufacture of this explosive was confined to three firms, of whom two were normally employed in the manufacture of dyestuffs and two only were accustomed to produce high-grade T.N.T. for military purposes. One of these two produced small quantities of a high-grade finely-powdered variety recently introduced as a filling for exploder-bags ; the other, a leading firm of explosive makers, produced a granulated T.N.T., which was purchased by the sub-contractor undertaking to load naval mines. On the other hand, the technique of cordite manufacture was well-known, and the explosive firms had little difficulty in training the personnel for their new cordite plant as it was erected.

The methods of manufacturing T.N.T. in use at the two contractors' works were slow and wasteful, involving the consumption of large quantities of oleum, the production of which in this country was very limited. Nothing was definitely known either as to the amount of the basic raw material, toluol, which would be available or as to the most efficient and economical processes of nitrating it up to T.N.T. The picric acid makers had been discouraged from extending their works by the knowledge that their produce was about to be abandoned. They lacked the will and the knowledge to turn over to the manufacture of T.N.T., nor could their plant be adapted for making the new explosive. There existed, however, large stocks of a commercial product capable of conversion into service T.N.T. by a difficult and dangerous process. These were held by the dye-stuff maker already contracting for the service explosive and by another firm, which was closely allied to a Swiss company and made dyes for export.

III. Organisation of High Explosive Supply.

The War Office, faced with the need for immediate purchases of large quantities of a novel explosive on behalf of both services, called in expert advisers. A Committee on High Explosives, with Lord Moulton as chairman, was formed by the Board of Trade at the request of the Army Council on 16 November, 1914. Its functions were at first purely advisory and related mainly to the supply of raw materials, particularly toluol, and the acids which were essential for making not only high explosives, but also propulsive explosives. Towards the end of November, 1914, the Committee had thoroughly examined the position and had recommended the requisitioning of the country's whole output of toluol. Power to do so was taken by a clause inserted in committee in the Defence of the Realm (Consolidation) Act, on 23 November, 1914. Meantime, the Contracts Department, acting with and without the advice of the Committee on High Explosives, had taken certain emergency measures to procure a supply of T.N.T., acquiring all the toluol available, placing large orders with inexperienced firms and sanctioning the erection of plant laid out along French lines of manufacture pending the development of a more efficient and economical process by the Research Department at Woolwich. The orders for picric acid which had at first been restricted to early deliveries were extended over a longer period. On the day after the Defence of the Realm (Consolidation) Act passed into law, chemical works at Rainham were acquired for purifying the available stocks of commercial T.N.T. under an agency agreement.

It was evident that active intervention in an extremely technical industry would be needed to organise the supply of T.N.T. and of the raw materials for explosives. The duties to be undertaken included the control of raw materials, the output of which might be requisitioned under the Defence of the Realm (Consolidation) Act, arrangements for transport, inspection and storage of products under special circumstances and a complex system of accounting for the toluol issued to contractors and for the finished explosive used on behalf of one or other of the two services. A strong body of opinion existed in favour of establishing Lord Moulton's Committee as a distinct Department of State, or at least, as an independent branch within the War Office responsible to the Army Council alone for the expenditure of a distinct section of the army vote. After several weeks' delay, the Committee was invested with executive power under an administrative compromise, whereby it was combined with a newly-established branch of the Directorate of Artillery, its expenditure was assigned to the vote of the Master General of Ordnance and the branch itself controlled by his representative, Brigadier-General Savile, in conjunction with Lord Moulton. By this means the War Department remained responsible for the supply of high explosives for both services and acquired the duty of providing raw materials common to both classes of explosive, an arrangement sanctioned by the Admiralty in January, 1915. The publicity and delays inherent in establishing a new Department of State were avoided. A financial officer was detached from the Finance Branch of the Master General

of Ordnance to regulate the system of accounting along the established lines. Lord Moulton at once set about developing the country's capacity for manufacturing high explosives to the utmost limits, restricting his efforts only by the amount of coal-tar products available and intending to dispose of any surplus products to the Allies, who were daily clamouring for assistance in this respect. He thus attained independence of the variable demand from military authorities, whose requests for high explosive changed with shifting conditions in the field, and with divisions of opinion as to the value of high explosive shell. In view of the urgency of the occasion, and supported by common knowledge that the enemy was using high explosive in immense quantities, he gave to his functions their highest value of autonomy. His schemes involved the erection of large national works for making T.N.T. from Borneo petroleum, the close supervision of manufacture at contractors' works by skilled inspectors, the development of the country's resources for deriving explosive materials from coal-tar and the introduction of the synthetic manufacture of phenol to supplement the natural carbolic acid already utilised to the full in the production of picric acid. Pending the construction of the new plant, considerable quantities of high explosives were purchased at inflated prices from the United States of America as a purely temporary measure.

IV. Methods of Obtaining Propulsive Explosives.

The policy adopted in regard to propulsive explosives was very different. The industry was already well established. The two departments continued to place orders separately for their several requirements, and to share the output of the Royal Gunpowder Factory until January, 1915, when a threatened shortage of cordite to meet the naval programme for the last six months of the year arose partly from the allocation of increased capacity to the army. The Admiralty make a bid for independence by constructing the Royal Naval Cordite Factory at Holton Heath, but the progress of construction was too slow to make good the expected deficit. Both the First Lord (Mr. Churchill) and the Secretary of State for War (Lord Kitchener) favoured the union of the supply of propulsive explosives for both services as a means of economising the country's resources. A scheme for supplementing the Royal Naval Cordite Factory by converting derelict works at Queen's Ferry into a national guncotton factory was accordingly initiated by Lord Moulton in February, 1915. The *rapprochement* between the two departments disappeared with the resignation of Mr. Churchill in May, 1915. Independent plans for expanding the production of naval cordite were made on behalf of the Admiralty by an expert adviser, Sir Frederic Nathan, whose appointment served still further to render the Admiralty self-contained in this respect. Meanwhile, the Munitions of War Committee, investigating the position of the supply of propellants for both services, recommended that large quantities of some substitute propellant should be produced for the army in order to free for naval use service

cordite, the stability of which had been well tested. From this proposal sprang the great national factory at Gretna, planned to make "R.D.B.," a new type of cordite. The execution of the project was undertaken by Lord Moulton.

The High Explosives Branch of the War Department was absorbed into the Ministry of Munitions in the summer of 1915. Its former duties were increased by the responsibility for supplying military propulsive explosives, but the Admiralty continued its independence in regard to this class of explosive, save only so far as the supply of raw materials was concerned.

V. The Use of Substitutes.

In March, 1915, the army had already accepted an American "single base" propellant for restricted use in ordnance and general use in small arms. Shortly afterwards (in April) certain proportions of ammonium nitrate mixtures were sanctioned for use in land service shell as a means of economising T.N.T. Until these changes were made, the choice of the explosive to be used had been regulated by considerations of efficiency and safety alone. The grave results of such a practice had been experienced in the previous autumn, when a complete absence of the means for obtaining an immediate supply of the chosen explosive (T.N.T.) was discovered at the last moment. Disaster was only avoided, in this case by superhuman efforts applied to the planning and construction of new plant, and to the organisation of supplies of raw material, and by concentrating into a few months scientific research which would normally have covered a period of some years. As it was, supplies of explosives kept pace with the demand or outpassed it, but they only did so during the winter of 1914-15, because the demand itself was limited by delays in the production of empty shell. When once it had been accepted that it was necessary to consider the country's resources in laying down which explosives were to be used, the adoption of alternative high explosives or propellants advanced steadily, though slowly. By the autumn of 1915, ammonium nitrate mixtures in the smaller proportions (40/60) had been accepted in all land service shell and in the larger proportion (80/20) for certain classes of 18-pdr. shell, while new filling factories were being erected to facilitate its adoption in larger natures and technical difficulties were being closely studied. These were finally overcome by the erection of suitable filling factories under the Ministry of Munitions and by close study of the mixing and loading of 80/20, which by the end of 1917 had proved this explosive to be of equal efficiency with T.N.T. as well as more economical in its production. Orders for American nitro-cellulose powder increased rapidly, and its manufacture was inaugurated in Canada. The army thus came to depend upon overseas supplies of this explosive for 50 per cent. of its total requirement for propulsive explosives; while the country gradually became self-contained in respect of high explosives.

VI. Raw Materials as the Controlling Factor in Explosive Supply.

This difference in the treatment of the two classes of explosives rested on a common circumstance, viz., the final government of supply by the amount of raw materials available. The creation or extension of explosives plants was carried out early in the war, before constructional work was subjected to any grave restrictions. The labour for explosives factories was drawn from the ranks of the unskilled and trained in the works themselves. Technical staff was gathered from the Universities, or drawn from all parts of the Empire, and trained in the new factories as they were erected. The provision of an adequate supply of raw materials was from the very first the limiting factor in output and increased in difficulty as time went on.

High explosives depended upon the provision of coal-tar products, in which the country was prolific, and upon acids manufactured from sodium nitrate imported from South America and from pyrites brought from Spain. Home supplies of coal-tar, toluol and phenol were also supplemented by distilling the one from Borneo petroleum and by the synthetic manufacture of the other out of benzol. The home production of T.N.T. was continued to the limits of the toluol available until the close of the war. Picric acid was practically abandoned in 1918, not only because of the extra safeguards needed in making and handling it, but because its manufacture was comparatively wasteful of money and materials. The use of ammonium nitrate mixtures increased during 1917 and 1918, since ammonia was a home product. The technical difficulties which hampered an adoption of ammonium perchlorate mixtures were still under discussion when hostilities ceased. Had it been possible to render these mixtures less sensitive to rifle fire and to premature explosion on set-back in the gun, the services might have been supplied with high explosives, absolutely independent of imports. The costly purchases of American T.N.T. ceased towards the end of 1917. They were not resumed to meet the restrictions in tonnage due to the submarine campaign, since so large a proportion of the raw materials required for high explosives were of home production and thus no material advantage could be obtained by shipping the completed article instead of bulky raw materials.

On the other hand, all the materials used in making propulsive explosives were either imported from abroad or produced at the expense of food supplies. At the first, difficulty was chiefly anticipated in regard to the solvent acetone, a product of wood distillation in America, and essential to the manufacture of service cordite of the stability upon which the Admiralty insisted. In view of the extreme delicacy of the acetone market, the army began to use nitrocellulose powder in the spring of 1915 and adopted also cordite R.D.B., made from ether-alcohol instead of acetone. Nitrocellulose powder was a "single-base" explosive, having the advantage that it needed no glycerine ; but its stability was under suspicion, knowledge of the method of production was lacking, and considerable structural alterations would have been needed to convert existing cordite plant for its manufacture. Hence, it was decided in the emergency of

1915, rather to make the modified form of cordite than to change over existing plant to nitro cellulose powder, or even to lay out the new factories, such as Gretna, for this purpose. The position in respect to glycerine was then fairly safe. It was being made in considerable quantities as a bye-product of the soap trade and reserves were built up without difficulty until it became necessary in the autumn of 1917 to divert a greater proportion of the imported oils and fats to the manufacture of margarine rather than soap. Towards the end of 1916, uncertainty as to the attitude of the United States led to projects for the home manufacture of nitrocellulose powder on a large scale. With the entry of America into the war in the following April and the growing stringency of the shipping position, these schemes were abandoned except for the erection of a single, comparatively small, factory (Irvine), which was given low priority and only began producing towards the end of the war. It was more economical of tonnage to import the completed nitrocellulose powder than the raw materials, particularly the sodium nitrate, for its production at home. Accordingly, large purchases were still made in the United States during 1917. Moreover, for the same reason, when shipping difficulties further reduced the gun ammunition programme towards the end of 1917, it was found necessary to close down 50 per cent. of the home capacity for cordite manufacture, and to rely on shipments of nitrocellulose powder, although even these were spread over longer periods. Thus, at the close of the war, home capacity which had been subsidised by the State, lay idle, while large quantities of propellants were being made on American plant in competition with Allied demands, and purchased by Great Britain under extremely disadvantageous financial conditions.

VII. State Manufacture.

Factories for making high explosives were the earliest of the new industrial establishments under direct State administration which owed their creation to the circumstances of the war. The lack of experienced makers of T.N.T., the technical nature of the process, and the need for elaborating the details of lay-out in the light of contemporary investigation, led to the erection of national factories for this explosive from January, 1915, onwards. The policy was justified by the comparative failure of the enterprises undertaken by inexperienced private firms, whose output was in some cases only assured by eventual nationalisation. During the summer of 1915, the number of State factories for T.N.T. production was increased on this and other counts, and mainly on the ground that central control of structural work was necessary to prevent undue competition for the special plant required. State factories for picric acid were erected early in 1917 in order to utilise surplus quantities of the raw material; but an earlier scheme for a large scale picric acid factory was eventually abandoned before production had begun.

Apart from the initiation of the Royal Naval Cordite Factory in January, 1915, and the concurrent establishment of guncotton works at Queen's Ferry, the first of the new State factories for propulsive explosives to be projected was Gretna, which was planned at the instance

of the Munitions of War Committee in May, 1915. Pembrey, a subsidised factory, erected and managed by the leading explosives makers (Nobel's), was the only other cordite factory added to the State establishments. The same firm built and managed, on behalf of the State, the one nitro-cellulose powder factory which came into operation late in 1918.

The cost of the new national explosives works was enormous, amounting in all to close upon £21,500,000, irrespective of the corresponding expenditure on national factories for the raw materials needed, such as the plant for synthetic phenol, and ammonium perchlorate, or the wood distillation factories. In some instances, such as Gretna and Queen's Ferry, this expenditure included large sums spent upon housing schemes. The method of payment for construction was originally based on the time-and-line principle to meet the urgency of the position in 1915, when the development of processes and lay-outs *pari passu* with the construction of the factories made it impracticable to pursue normal contract procedure. Applied to later factories, such as Avonmouth, this system of payment admittedly led not only to extravagance, but also to delay and inefficiency. The earlier factories came into operation with amazing rapidity; the progress of the later ones was hampered at every turn by the general stringency in the supply of labour and material.

An important object served in peace time by the one State factory at Waltham Abbey had been the evolution of a sound works practice for novel forms of explosive. Thus, in conjunction with the Research Department, the Royal Gunpowder Factory had already worked out manufacturing methods for service cordite and for tetryl, and during the war it carried out a considerable amount of experimental work on fuse compositions. In this, it served one of the main purposes of an Ordnance Factory by executing experimental orders and providing for some of the small experimental requirements which were not readily undertaken by contractors. The local conditions of the factory and its piece-meal lay-out, however, hampered its expansion with the new needs of the war, and prevented it from serving as an unquestioned check on contractors' costs and efficiencies.

Both of these primary functions of a State factory were assumed by the new national explosives works built during the war. The Royal Gunpowder Factory had never been concerned with high explosive manufacture; manufacturing methods for the new high explosive, T.N.T., were accordingly worked out at first on a semi-manufacturing scale, and under quite abnormal circumstances, by the Research Department at Woolwich, and afterwards on a much larger scale by the new national factories at Oldbury and Queen's Ferry. Satisfactory methods of making and using ammonium nitrate mixtures were similarly initiated by the Research Department and subsequently developed by the National Filling Factories set up by the Ministry of Munitions. In the absence of a State factory able at once to work out the manufacturing methods for R.D.B. cordite, this problem devolved upon the established cordite firms and occupied six months. The development of works practice for nitrocellulose powder manufacture was the work of a State factory under the management of

Nobel's Explosive Company, whose relations with the American makers greatly facilitated the introduction of this industry into Great Britain. Most of the new national factories undertook a certain amount of research; some of them, such as Oldbury, were specially equipped for investigations outside the routine work allocated to them. It is difficult to assess the value of such experimental work. Its fundamental importance is, however, undeniable, and its utility is particularly obvious in the case of explosives manufacture, where the initial lay-out and construction of the plant have an unalterable influence upon efficiency and economy in subsequent production.

A more direct justification for the immense expansion of State manufacture lay in consequent reductions in contract prices. The immediate alternative to the erection of the T.N.T. works in 1915 was to make large American purchases, and thus not only to become dependent upon a precarious source of supply but to compete with the Allies in a constantly rising market. At home the erection of the new plant by contractors was limited, in view of the urgent need for large and immediate production, by the comparative scarcity of efficient firms. The plant erected by those contractors who did undertake the work was either subsidised directly or paid for indirectly by inflation in the contract prices.

The construction of works on so large a scale as Queen's Ferry, Gretna, or Oldbury, went to cheapness in production, but these were ventures which would scarcely have been undertaken by any individual firm. When once State factories were in full operation it was possible to use the results of a thorough system of cost accounting as a means of checking the profits made by contractors. The supply department was thus provided with an exact knowledge and no longer bargained in the dark, while the very existence of State capacity counted towards independence of a small, and in some instances, a closely organised industry. The actual reductions in the prices for T.N.T. which were effected in 1917 were based on the cost of production revealed by usage in the State factories. Concurrent decreases in the rates for propulsive explosives were based also on systematic returns from the contractors themselves. In both cases, there were working to the same end other causes, which will be considered below. It is, however, evident that the effect of State manufacture in reducing contract prices was most direct in the case of the novel industry of T.N.T. manufacture.

Similarly, it was the State factories for T.N.T. production which produced the most remarkable results as to efficiency and economy of material, and served as a high standard for the firms making under contract. In this respect, again, contractors for propulsive explosives held a somewhat different position. Their industry was well established. The firms were thoroughly familiar with the technique of cordite manufacture and were already accustomed to make detailed calculations of general efficiency and of their usage of raw materials.

The immediate purpose of the State factories was to assure immediate and enormous output. Their production of T.N.T. was eventually so great that it enabled trade capacity to be treated as a stand-by only, or as a mere margin, a diminution in the manufacture

of this explosive by the trade being in fact desirable because of the general unsuitability of the dye-works or chemical factories which had been converted to so dangerous an industry. The manufacture of picric acid by the State had scarcely been developed when its use was practically abandoned. The great cordite factory at Gretna was necessarily slow in completion. It attained its full normal output of 800 tons weekly early in 1917.

VIII. Relations with the Explosives Trade.

The main feature of the relations with the explosives industry was the gradual absorption of all trade risks by the State. From the very first it was found necessary to subsidise the new plant erected by contractors for both classes of explosives, and so to relieve them of any risk in regard to over-development. Many of the new firms undertaking T.N.T. manufacture from October, 1914, onwards, were unfamiliar with the market for the raw materials, and reasonable prices or assured output could in such cases only be obtained by such an arrangement as that made early in December, 1914, whereby the War Department undertook to provide raw materials for the Hackney Wick factory, then being started by a contractor. By purchasing the whole of the available toluol and phenol during the winter of 1914-15, and issuing them to contractors at fixed rates, the State became responsible for the supply of the basic raw material for all high explosives. A gradual assumption of control over the sulphuric acid industry culminated in the order of February, 1916, fixing maximum prices for the various grades of this acid. This measure automatically relieved explosive contractors also of risks in regard to nitric acid. The cordite firms were at first less dependent upon the State for an assured supply of solvents or cotton waste. In May, 1915, however, the purchase of acetone in the United States was concentrated in the hands of the War Department's agent to avoid confusion in a very delicate market, and a rise in the prices paid was refunded to the cordite makers in order to avoid any change in the price of the explosives. The increased gun ammunition programme of July, 1915, led to an order requisitioning the stock and output of glycerine in the following August. The cordite trade, concurrently with a multitude of other industries, benefited by the fixing of prices for sulphuric acid in February, 1916. Towards the end of that year it was decided to supply cordite makers with all the raw materials they required, and their cotton waste supplies were thenceforward under the control of the Ministry. When once the fixing of prices for raw materials lay with the Department, contractors were permitted to safeguard themselves against any rise in their cost by the introduction of a sliding scale into the contract price.

The danger risks peculiar to the explosive industry formed good ground for indefinite inflations of price on the part of contractors, whose liabilities for third-party risk and workmen's compensation were specially large and uncertain. Policies issued by the insurance companies through the intervention of the Ministry excluded these two risks, and even the premiums for this limited insurance were raised

by two-thirds as a result of a serious disaster in the spring of 1916. During that year, the acceptance of a certain amount of liability by the State became essential both as a means of inducing firms to continue so hazardous a manufacture and in order to ensure a general reduction in prices. The Munitions (Liability for Explosions) Act of December, 1916, enabled the Ministry to indemnify explosives makers in respect of third-party risks, a certain contribution being made by the firms. During the eleven months between June, 1917, and May, 1918, the levy made from contractors did not, however, cover the compensation payable by the department in respect of third-party risks.

During 1916 and 1917 very considerable reductions were effected in the price paid for all explosives. These were unquestionably the result of several causes, among which the removal of trade risks, particularly the risk of explosion, was of primary importance. At the same time, the amortisation of the original outlay on extensions undertaken by the contractors themselves was practically complete, and further extensions, which were limited by the stringency of the supply of building materials, plant and labour, were restricted to alterations frequently subsidised by the State and carried out with a view to economising raw materials. Again, the existence of the newly-established national factories greatly lessened the bargaining power of the contractors, and provided an exact means of checking their costs of production. Perhaps the most remarkable decrease in prices was that in the rates paid for cordite, which at the close of the war were considerably lower than contract prices in time of peace, even though the cost of materials had risen considerably and the cost of labour by at least 50 per cent.

A further circumstance which enabled the trade to decrease its prices was the general advance made in efficiency and particularly in the usage of raw materials. Until the decrease in the gun ammunition programme in 1917, the output of every pound of explosive was a matter of importance, and on this account the efficiency of the trade was the interest of the State. Even after the demand had been reduced the shortage of tonnage made an economical usage of imported materials the first concern of the Explosives Supply Department. As the Minister gradually strengthened his control over the supplies of raw materials, an insistence upon the best use of them became possible, and clauses were inserted into contracts fixing the minimum output of explosive to be made from a definite amount of material, the proportion being based on experience in the national factories. The enormous wastage of acids in 1914-15, due to lack of concentration plant in contractors' high explosive works, was corrected during 1916 by State subsidies for new plant. On the other hand, the cordite makers were induced to balance up their plant later in the year at their own cost, since it was to their own interest to increase output.

The peculiar relations between the Supply Department and the T.N.T. makers in regard to safety conditions strengthened the hand of the department in insisting upon satisfactory works practice until this explosive was brought within the terms of the Explosives Act in August, 1917. The novelty of this industry and the lack of experience of explosive manufacture among the dye-makers and others who took it up.

gave rise to that thorough system of inspection during production upon which Lord Moulton specially insisted in the autumn of 1914. Output of less essential products rather than of the explosives required for munition purposes was guarded against by these means, and by such measures as the assumption of control over all waste picric acid in the spring of 1916. Less frequently, and chiefly in 1915 when the urgency of output was particularly great, T.N.T. works in which inefficiency was well proved and safety conditions consistently disregarded were nationalised. The main method of securing efficiency was, however, the diffusion of knowledge. The national factories planned on the most advanced lines and competing with each other in a wholesome rivalry led the way in this respect. When once the barriers of commercial jealousy were broken down by the urgency of the general position in 1915, contractors followed suit.

IX. Summary of Production.

The total achievements in regard to explosive supply are summarised in the following table. It shows in short tons the yearly deliveries of high explosives for both services. The figures of propulsive explosives relate to the land service only, except during the months between August 1914 and June 1915, when they represent the deliveries on behalf of both the navy and the army.

DELIVERIES OF EXPLOSIVES, 1914-1918.[1]
(Short Tons.)

	1914 (Aug.-Dec.)	1915	1916	1917	1918	Total.
High Explosives (Picric Acid and T.N.T.)						
Home	434[2]	9,822[2]	58,420	94,785	79,098	242,559
Abroad ..	nil	2,183[2]	13,332	18,272	nil	33,787
Ammonium Nitrate[5]						
Home	nil	7,101[2]	51,158	135,355	124,011	317,625
Abroad ..	nil	1,100[2]	4,325	11,254	2,047	18,726
Total High Explosives	434[2]	20,206[2]	127,235	259,666	205,156	612,697
Propulsive Explosives (Cordite, Ballistite and N.C.T.).[2]						
Home	5,298[4]	12,438[4]	29,617	98,778	77,258	223,389
Abroad ..	nil	13,535[2,3,4]	54,594	106,031	52,938	227,098
Total Propulsive Explosives ..	5,298[4]	25,973[4]	84,211	204,809	130,196	450,487

[1] Figures represent despatches from manufacturers and arrivals from abroad in short tons, and are based upon D.M.R.S. Records for 1916-18, and upon various sources for 1914-15. (*See* HIST. REC./R/1500/19.)

[2] Figures of actual deliveries are not available. Approximate figures are here given.

[3] Inclusive of explosive in complete rounds from overseas.

[4] Inclusive of propulsive explosive for Naval Service.

[5] Used in conjunction with T.N.T. in proportions varying from 20 per cent. to 80 per cent.

At the close of 1918, the total stocks of high explosives were 44,000 tons, the stocks of propulsive explosives, 58,000 tons. No shortage of explosives had ever actually limited the supply of munitions, save for a few weeks in the autumn of 1915, when the restricted amount of tetryl available did for a time hold up the completion of gaines and hence of the finished shell. This attainment was the more remarkable in view of the conditions peculiar to the industry. The rapid development of dangerous operations on an enormous scale was not effected without disaster, loss of life and destruction of plant; but the provision of a margin of capacity, the continued and increasing insistence upon compliance with "safety" regulations, and an adaptability which invariably found a solution for new problems, combined with the loyalty of the workers in explosives factories to prevent catastrophe at home from reducing the supplies to the navy or the army.

The experience of the war had emphasized the absolute dependence of explosives supply upon two main factors, a sound technical knowledge concerning the manufacture and use of various types of explosives, and an adequate supply of the necessary raw materials. Starting almost *ab initio* in regard to high explosives, and applying to them an immense amount of concentrated research and practical investigation, the authorities concerned eventually succeeded in providing both the British and the Allied forces with safe and efficient high explosives, depending to a very restricted extent upon imported materials. Entire independence, however, still lay in the completion of such schemes as those for rendering ammonium perchlorate mixtures less sensitive and for obtaining nitric acid from the atmosphere on a commercial scale. Knowledge of manufacturing practice in regard to the standard propulsive explosives at the outbreak of war was far greater than that of high explosive production; but the dependence of the former class of explosive upon overseas supplies throughout the war was more remarkable. The modifications made in 1915 to meet the increased needs of the army were restricted to the elimination of one material, whose supply from America was then particularly precarious. The large plants erected at Gretna and Pembrey were laid out for making the form of cordite in which ether alcohol superseded acetone as a solvent, and the double base explosive of nitrocotton and nitroglycerine was retained, since British experience related only to double-base powders, and their known stability rendered them particularly acceptable to the services. At the same time, it was necessary to draw upon supplementary supplies of a single-base (nitrocellulose) powder purchased from America in quantities, which equalled the output of cordite at home. This explosive was only serviceable on the western front; but its importation was continued in the face of financial difficulties during 1917 and 1918, when restrictions in programme had enforced the closing down of half the home capacity for cordite. This policy was only due to the stringency of the shipping position. With the development of the submarine campaign, the use of fats in the production of glycerine or grain in making alcohol was gradually restricted in the interests of food supply. Since nitrocellulose powder took up far less tonnage than the raw materials for its manufacture, schemes set on

foot for its manufacture at home were reduced to the erection of a single comparatively small factory. At the close of the war a great part of the home capacity for propulsive explosives thus lay idle on account of economic conditions.

Such changes as were effected to meet the shifting circumstances of the war were carried through in the face of many practical difficulties. On the one hand, modifications in the types of explosive used, though essential to an adequate supply, involved far-reaching changes in methods of filling and detonation. On the other, any alteration affecting ballistics was out of the question in either service, and the introduction of new powders whose qualities were suspected or unproven was undesirable. Years of experience were the best proof of stability in the eyes of the navy and the army. Although some diminution in the high standard set was feasible for the explosives to be used immediately on the western front, the stability of Admiralty supplies, and those for use in the hotter climates of the British Empire, had to be unquestioned. In view of these conditions, the consideration of the economic resources of the country was apt to take a secondary place until from time to time its urgency became undeniable.

It would be unjustifiable to attempt here to pass judgment upon the individual achievements which reached so great an aggregate. The results attained are so great that they have thrown into a comparatively dim background the grim features of the crisis of 1914-15. Yet the problems of that time can hardly be over estimated. The very success of the efforts then made has tended to obliterate the difficulties which confronted the technical experts, lawyers and business men from every part of the Empire, who united to organise *ab initio* the chemical resources of the country.

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THE SUPPLY OF MUNITIONS

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GUN AMMUNITION: FILLING AND COMPLETING

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CHAPTER I.

INTRODUCTION.

I. Nature of the Operations needed for Completing Gun Ammunition.

The foregoing accounts of shell manufacture[1] and explosives supply[2] have dealt with those important stages in producing gun ammunition whereby the main units of the round were provided. The final operations which normally occupied at least two months and often longer, played an equally important part in the supply of ammunition and had grave practical difficulties peculiar to themselves. Unceasing carefulness on the part of the individual worker was necessary to ensure efficiency and safety in the finished product. Almost every operation was carried out under peculiar risks of fire or explosion, and some endangered the health of the workers unless proper precautions were taken.

The empty shells and the necessary explosives were sent to filling and assembling factories. Shrapnel shells arrived with their bullets, central tubes and cups already in position, only needing the insertion of the powder burster. High explosive shells required filling with the bursting charge of picric acid, tri-nitro-toluene (T.N.T.), or amatol, a mixture of from 80 to 40 per cent. of ammonium nitrate with T.N.T. The smaller natures, both of shrapnel and H.E. shell, which were issued as quick-firing or fixed ammunition were assembled in the factories at home. The cartridge case was placed on a bench with a dummy primer in the primer hole. A cartridge charge of cordite or nitro-cellulose powder was inserted in the case, the loaded shell was pushed into place by a vertical hand press and the case was fixed on to the shell in a coning machine. The dummy primer was then removed and the service primer screwed into the cartridge, the fuse and gaine were screwed into the shell, a safety clip to protect the cap of the primer was sprung over the base of the cartridge case, and the complete round of ammunition was finally boxed for issue. The larger natures, commonly known as breech-loading ammunition, were assembled in the field. Before issue, the propellant was made up into cartridges being generally placed in a bag into which an igniter was sewn. The shells were filled and plugged. The fuses were filled and assembled, work involving numerous small operations which needed great precision and care,

[1] Vol. X, Part III.
[2] Vol. X, Part IV.

since an extremely large proportion of the prematures which occur arise from a defective fuse.

The final stages of production were the supreme test of good organisation, since any irregularity in the supply of a single component or of any one of the numerous minor items rendered nugatory all the effort expended on the rest of the round. The whole of these operations were enormous in number and complex in kind. They depended upon the due supply of the last minor component in an enormous scheme of peddling out.[1] Shells, explosives, fuses, gaines, detonators, cartridge cases, primers, and large quantities of packages, silk, straw-board, paper, paint, cement, and other materials of strictly specified sizes and qualities had to be brought together at the right time and place. A complete round of a single nature, viz., the 18-pdr. H.E., consisted of 15 cartridge components, 52 fuse components and 11 shell components. Any fault in the regular flow of the least of these numerous items was liable to hold up the whole programme of ammunition supply, and in the majority of cases the first shock of the failure was felt by the filling and assembling factories. The work of these factories was equally hampered by a shortage or a surplus. The problem was not merely concerned with the organisation of transport and storage and the building up of stocks. Changes in design, made with a view to greater safety or efficiency or in order to meet a shortage of materials, led to constant alterations in the strict specifications which regulated the size and quality of everyone of the articles needed. An extreme instance of the reaction of such changes upon the work of completing ammunition occurred towards the end of 1915, when the filling and assembling of 18-pdr. H.E. shells was entirely suspended for about six weeks pending organisation of the supply of the newly designed 10-grain detonator.[2] Again, the exigencies of the military position might, and frequently did, so change the class of the components to be used with particular natures of shell, that the whole programme of supply, however carefully it had been balanced, would thereby be overset. These changes bore particularly hardly upon the organisation for completing ammunition, where any failure in the regular supply of every component was most definitely apparent. The methods used for manufacturing and filling components will be treated below as an essential and important part of the business of completing ammunition.[3]

II. Methods of Filling H.E. Shells and Components.

The methods used for filling shells with high explosives were peculiarly subject to change, because new kinds of explosive were adopted and because the problem of detonation was subjected to concentrated research during the war. The main features of these developments have already been described.[4] It will be sufficient here

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[1] Mr. Geddes, 11.2.16 (C.R. 3008)
[2] C.R. 3008.
[3] Chap. V
[4] Vol. X, Part IV, Chap. I

to recapitulate briefly their effects upon the practice used in filling factories. During the first 18 months of the war melt-filling was the chief method used for picric acid, T.N.T. and for amatol, in which the proportion of T.N.T. was 60 per cent., *i.e.*, amatol 40/60.[1] These explosives were brought to a liquid state by heating, were poured into the shell, and allowed to cool. The main exception to this practice was block-filling, a method generally introduced for amatol in 18-pdr. shells in May, 1915, and then already in use by one firm (Explosives Loading Company) for T.N.T. The disadvantage of block-filling in the smaller natures was that it entailed the manufacture of shells with cavities of the same diameter throughout as the fuse-holes, or else with removable heads or base plugs of the same diameter as the cavities. Its adoption in larger natures was under discussion until January, 1916, when the project was abandoned owing to difficulty experienced in obtaining satisfactory detonation. The main advantage of block-filling was that it facilitated the use of amatol containing considerably less T.N.T. In September, 1915, it was estimated that a part of the gun ammunition programme for 1917 would depend upon the use of amatol 80/20, *i.e.*, amatol in which the proportion of T.N.T. was reduced to 20 per cent. It was at this period considered impracticable to fill with 80/20 amatol made by "hot-mixing" and the alternative, therefore, to block-filling was the French method of hand-stemming the cold explosive as a powder and compressing it in the shell by means of a wooden mallet or by hydraulic pressure. A few presses were installed at the Ordnance Factory about July, 1915, for pressing 80/20 amatol into 18-pdr. shells in one operation. A British mission, which was appointed by Mr. Lloyd George to study French methods of shell-filling in October, 1915, recommended that all natures should be filled by pressing the charge of cold 80/20 amatol direct into the nose of the shell, but that the French methods of hand-stemming the powder into the shell preparatory to pressing could be materially improved by using mechanical means.[2] The final decision in favour of pressing 80/20 amatol charges in larger natures instead of block-filling was given on 25 January, 1916, as a result of trials of shells filled by the methods of mixing and pressing developed at the Chilwell National Filling Factory. Meanwhile duplicate melt-filling plant for 40/60 amatol was installed at the new filling factories which were being erected by the Ministry of Munitions.[3] The buildings containing this melt-plant were subsequently utilized as far as possible for filling with hot 80/20 amatol by a new process which was worked out at the Georgetown National Filling Factory in July, 1916. A mechanical apparatus for stemming powder into shell was developed towards the end of that year, and screw-filling machines were installed in the national factories

[1] Amatol 40/60 was made by introducing ammonium nitrate into steam-heated vessels containing molten T.N.T., thoroughly mixing, and then pouring the mixture into the shell as with picric acid and T.N.T. The ammonium nitrate does not melt except at temperatures far above that to which it is prudent to heat T.N.T., and a mixture containing more than about 40 per cent. of ammonium nitrate becomes, therefore, too viscous to pour readily.

[2] HIST. REC./R/1340/10 ; C.R. 2830.

[3] *Ordnance Committee Minute* 385 ; *see* below, Chap. III.

early in 1917. These later changes were the result of practical experience and of systematic investigations which brought the quality of gun ammunition up to an extremely high level and are described below.[1]

III. Departmental Organisation for Filling and Assembling Gun Ammunition.

From August, 1914, until June, 1915, the responsibility for filling and completing the bulk of the gun ammunition produced rested with the Chief Superintendent of Ordnance Factories, while the contracts officers concerned with gun ammunition (Section " A.7," formerly " Contracts 1A ") negotiated orders for filling and assembling, from November, 1914, onwards, when certain contractors undertook to provide complete rounds.[2] When the Ministry of Munitions was formed in June, 1915, the duties of filling and completing ammunition were allocated to the department which was concerned with shell manufacture and was controlled by Mr. (afterwards Sir Glynn) West, Deputy Director-General (A). He established a filling section A.M.4, to be known as the " Cartridge, Fuse and Shell Filling and Assembling Department." The new section was formed on 17 July, 1915. It was under the control of Major (now Colonel) H. B. Strange, R.A., who had had experience in controlling the manufacture and inspection of munitions, both at Ordnance Factories and also at private works, and in organising transport during the South African War. His duties concerned all the operations necessary to the completion of gun ammunition, and also the storage of the completed ammunition pending issue. He was also responsible for the manufacture of packing-cases for cartridges.[3] During his term of office, the main work of the section was the initiation of the great National Filling Factories, which were first planned at the end of July, 1915, as a means of completing the enormous quantities of gun ammunition anticipated from the new shell-manufacturing programmes of the Ministry.[4]

In August, 1915, Section A.M.4 became responsible for the storage of all munitions components and materials, the bulk of which were destined for the new filling factories. A committee of officers within A.M.4 allocated the stores and components to their different destinations, while a system for their circulation to contractors and national factories was begun early in October, 1915.[5] In this respect, the section occupied towards the new factories and the trade fillers the position held by the Deputy Director of Ordnance Stores, Woolwich, in regard to the Ordnance Factories. The Ordnance Factories themselves were transferred to the Ministry of Munitions in August, 1915. They were controlled by Mr. (afterwards Sir Eric) Geddes, Deputy Director-General (C), and continued throughout the year to be the main source of supply for filled ammunition and components and to

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[1] *See* Chap. IV.
[2] *See* below, Chap. II.
[3] C.R./Filling/155.
[4] *See* below, Chap. III.
[5] For the details of this scheme, *see* Hist. Rec./H/1340/1, Part I, Chap. IX.

draw their supplies of minor stores and materials through the Ordnance Stores, Woolwich, and from the riverside factories.

Towards the end of 1915, the dominating feature of the gun ammunition position was a general falling off in the issues of complete H.E. ammunition, which was chiefly attributable to shortage in the supply of minor components.[1] A general reorganisation of the head-quarters staff for completing ammunition accordingly took place with a view to lessening the time lost between manufacture of the empty shell and issue of the complete round, and in order to place upon sound lines the procedure for balancing and circulating components.[2] Responsibility for filling and completing gun ammunition was transferred on 28 December, 1915, to Mr. Geddes, who thus administered both the Ordnance Factories at Woolwich and also the new and gigantic capacity for filling and assembling, which was in process of creation. The main features in the reorganisation were the strengthening of the staff by the addition of experienced officers and the division of its duties among definite sections. Separate sections of the department, which was known as C.M.4, were established to deal with the programme for gun ammunition filling and to regulate the allocation of work and components between the various factories. A special section was also formed to advise upon the intricate technicalities involved in filling and assembling ammunition, while the work of supplying textiles and other materials and administering storage and the circulation of stores was entirely rearranged.[3]

Under the administration of Mr. Geddes, the construction of the National Filling Factories planned in the previous year was hastened, extensions to the filling capacity were made and operations began in the new shell-filling factories.[4] In May, 1916, he obtained sanction for a scheme whereby the supplies of shells, explosives and components to the filling factories were to be regulated in accordance with a forecast based upon the estimated capacity for filling and assembling rather than upon the final gun ammunition programme to which the various supply departments were working. It was thus intended to prevent large surpluses, to economise storage and to limit the amounts of money locked up in stocks, which were not of immediate use. In the same month, it was arranged that questions relating to the filling designs, which were normally submitted to the Chief Superintendent of Ordnance Factories for criticisms based upon practice, should also be submitted to the head of the Filling Department, in order that the experience of the new filling factories should be taken into account.[5]

In July, 1916, upon the appointment of Mr. Geddes as Director-General of Military Railways, the administration of the department was undertaken by Lt.-Colonel (later Brigadier-General) L. C. P. Milman, R.A., who had been in charge of the allocation section since the previous January. The duties of Deputy Director-General (C)'s

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1 C.R. 3008; *see* below, Chap. V.
2 C.R. 4514.
3 For the details of the organisation, *see* HIST. REC./H/1340/2.
4 *See* below, Chap. III.
5 HIST. REC./H/1340/3, Chap. III.

division were simultaneously reorganised and the control of the Ordnance Factories was again severed from that of the new filling capacity, being directly administered from the Munitions Supply Department. In the following November, when the Munitions Supply Department was reorganised as three divisions, both the control of the Ordnance Factories and the administration of filling and assembling were assigned to the Director-General of Ordnance Supply, Mr. (afterwards Sir Charles) Ellis. Department "C.M.4" became the Gun Ammunition Filling Department and remained under the control of Lt.-Colonel Milman. Until April, 1917, the duties of the department had included the function of store-keeping assigned originally to Colonel Strange in July, 1915. The responsibility for store-keeping and accounting, apart from the circulation of components to filling factories, was transferred to the newly formed Central Stores Branch of the Ministry in May, 1917. Again, in August, 1917, the department's duties in respect to providing packages and timber for various other munitions as well as for filled ammunition were undertaken by a distinct department directly responsible to the Director-General of Ordnance Supply.[1]

During the last two and a half years of the war, Colonel Milman's department was chiefly occupied with the solution of the difficult administrative problems, which characterise the final operations in producing gun ammunition and are described in detail below.[2] These concerned mainly the training and control of labour engaged upon a very special class of work and the careful supervision of factory practice and method with a view to ensuring safety and to improving the quality of the ammunition. Separate labour and medical sections were established to deal with conditions in the factories in September, 1916. The Technical Section was gradually strengthened, and in March, 1917, a separate unit was temporarily established for dealing with filling machines and other mechanical means for reducing the handling of poisonous explosives and improving efficiency generally.[3] The work of the department was enlarged in the spring of 1918. Upon the break-up of the Trench Warfare Supply Department at that time, the Gun Ammunition Filling Department became responsible for the filling not only of grenades and trench mortar ammunition, but also of aircraft bombs. At the same time, the processes of assembling chemical projectiles and loading them with their bursting charges were transferred to the department from the Chemical Supply Section of the Trench Warfare Supply Department, and in certain instances this duty was extended to include the charging of lethal substances into the projectile.[4] Finally, at the close of hostilities, many of the factories controlled by the department were turned over to the breaking down of filled ammunition, and the department itself was absorbed into the Condemned Munitions Recovery Department in March, 1919.[5]

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[1] Hist. Rec./H/1340/2.
[2] See Chap. IV.
[3] Hist. Rec./H/1340/2.
[4] See Vol. XI, Part II.
[5] General Memorandum No. 177.

CHAPTER II.

THE WORK OF THE ROYAL ARSENAL AND THE TRADE, 1914–1915.

I. Filling Capacity at the Outbreak of War.

The filling factories at the Royal Laboratory, Woolwich, were responsible under normal peace conditions for filling 40 to 50 per cent. of the naval H.E. shell and all the land service H.E. shell. The Royal Laboratory also undertook a very large proportion of the work involved in completing all classes of shell, *e.g.*, the assembling of shrapnel shell together with the filling of cartridges, fuses, detonators, tubes and other minor components. The remainder of the naval H.E. shell were filled at the outstations at Chatham, Portsmouth, and Plymouth.[1] A few firms were engaged in filling fuses and minor components for land service.

The comparatively small shell-filling capacity of the country, outside these limits, was chiefly engaged upon foreign orders. Thus, Messrs. Vickers, Ltd., Messrs. Thomas Firth & Sons, the Thames Ammunition Works, and the Explosives Loading Company were accustomed to take orders for loaded shell from foreign Governments.[2] The Explosives Loading Company had been formed in 1912 for the express purpose of charging shells, mines, and torpedoes with T.N.T., but had only received certain experimental orders from British authorities.[3] During the South African War, one armament firm (Messrs. Armstrong, Whitworth) had filled shell with lyddite[4] at Scotswood. This factory was placed at the disposal of the Admiralty at the outbreak of war, and a part of it was afterwards engaged upon the filling of 6-inch shells for the Army.[5] Certain of the remaining capacity was also taken up for naval purposes. For instance, the Explosives Loading Company undertook in October, 1914, to load naval mines at their Faversham works, which were capable of handling 100,000 lb. of T.N.T. weekly.

II. Extensions at Woolwich.

It was at first considered that sole reliance should be placed upon the Royal Laboratory for filling H.E. shell for the land service. At the outbreak of war, filling operations there were undertaken in two

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[1] Sec./Gen./2239.
[2] Hist. Rec./H/1340/1.
[3] Hist. Rec./R/1124/6 ; *ibid.*, 1500/15.
[4] 70/Gen. Nos./2401.
[5] Hist. Rec./R/1340/19.

sections of a new lyddité establishment and a part of the old lyddite buildings. The filling capacity of the factory was, in fact, considerably in excess of its corresponding manufacturing plant, so that it was able to undertake the filling of articles supplied by the trade.[1] The greater part of the work consisted in the loading of large naval shell with picric acid, an operation which was resumed on 31 July, 1914, after suspension due to prematures. Steps were immediately taken to bring output up to maximum capacity by the general introduction of overtime and nightshifts. Within a single week the melt-plant, which was normally accustomed to fill 10,000 lb. weekly and had never handled more than 30,000 lb. weekly, began to consume 100,000 lb.[2] per week. In the following October developments in the use of H.E. shell in the field together with the decision to fill large natures with T.N.T. made it necessary to erect two T.N.T. filling sections. The new buildings came into use about 15 April, 1915. The whole of the one section was working by the end of May, 1915 ; the second was completed by the end of September, 1915. In the meantime the lyddite establishment had been extended and certain of the lyddite melt-plant had been turned over to T.N.T. filling, since both explosives could be run molten into the shell. In July, 1915, it was expected that the ultimate capacity of these extensions to the melt-plant would enable the Royal Laboratory filling factories to deal with 200,000 lb. of explosive weekly for the two Services.

The lack of hydraulic presses at Woolwich was an obstacle to the introduction of any substitute explosive which was incapable of filling as melt in the same manner as picric acid or T.N.T. In January, 1915, it was accordingly laid down that in the event of the introduction of any other high explosive, filling would necessarily be undertaken elsewhere than at the Ordnance Factory.[3] Two means were, however, found for utilising the Ordnance Factory for filling with ammonium nitrate mixtures. Firstly, blocks of amatol were compressed by the Explosives Loading Company and Curtis's and Harvey, and sent in papier mâché containers to the Ordnance Factory for insertion into those 18-pdr. shell which were of the new design, having cavities with parallel walls.[4] Secondly, by keeping the proportion of ammonium nitrate used with T.N.T. to below one-half, the mixture when hot was liquid enough to be poured as a kind of porridge. The melt-plant at Woolwich could thus be used for 40/60 amatol in the small natures for which it was approved, and the turn-over from T.N.T. to 40/60 was complete by 25 June, 1915, so far as the 18-pdr. were concerned.[5] To cope with the hygroscopicity of the new explosive, drying plant was improvised out of melting-pans, steam-heated ovens and parts of the picric acid melting stoves, pending the arrival of Hind and Lund machines. The efficiency of these machines was then problematical ; but their installation in the following October reduced immensely the difficulties

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[1] 75/3/2357.
[2] Sec./Gen./2239.
[3] 74/H.E./25.
[4] *Ordnance Board Minute* 13,004.
[5] 74/H.E.T./92.

of working with inexperienced labour upon a make-shift plant. Three presses were also installed at Woolwich in the summer of 1915, in order to fill 80/20 amatol into 18-pdr. shells, and by the end of the year the plant for filling by this method was able to turn out about 35,000 18-pdr. or 13-pdr. shells weekly.[1]

Extensions for filling components were also effected at the Royal Laboratory. Additions were made to the primer branch, cannon cartridge buildings, quick-firing cartridge factories and cap and detonator factories, and magazine accommodation was correspondingly increased.[2] Three separate extensions to deal with fuses, gaines, and minor components were begun respectively in May, June, and July, 1915.[3] The Ordnance Factory's capacity for fuses and gaines was, however, rapidly absorbed by increasing demands and on 31 July, 1915, the Army Council notified the Minister that no filling capacity for these two components existed at the Royal Laboratory, beyond that already occupied for Admiralty and War Office orders.[4] The Ordnance Factories were then able to fill 102,500 shells, 95,000 cartridges, and 60,000 fuses weekly in addition to minor components such as gaines and primers.[5]

Further extensions for filling both shells and components were planned at the Royal Laboratory in August, 1915, when control was about to be transferred to the Ministry of Munitions, and a new cartridge-filling and assembling factory to double existing capacity was erected during the autumn, being laid out for assembling weekly 100,000 18-pdr. shells, either shrapnel or block-filled.[6] During the year 1916 there was considerable delay in allocating full work to this assembling factory owing to the general shortage of components.[7] The assembling of chemical shells, which was undertaken at Woolwich in the spring of 1916, was subsequently transferred to a separate factory at Greenford for safety's sake,[8] and the Ordnance Factory was thus enabled in the winter of 1916 to extend its capacity for assembling H.E. and shrapnel 18-pdr. shells.[9] During the last two years of the war, arrangements were gradually made for converting a part of the melt-filling capacity of the Ordnance Factory to hot-mixed filling with 80/20 amatol.[10] Lack of hydraulic presses, however, rendered the capacity of the Factory more suited to naval than military work and the proportion of the Admiralty filling undertaken increased,[11] while the land service filling diminished with the development of the National Filling Factories. Upon at least two occasions, however, the filling and assembling shops at Woolwich played a dramatic part

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1 HIST. REC./H/1520/6, p. 10 ; D.D.G. (A) 9888.
2 Sec./Gen./2239.
3 C.R. 4436.
4 C.R./D.G.S.G./18.
5 HIST. REC./R/1400/3.
6 D.D.G. (A) 9888, 12859.
7 D.D.G. (C)/C.M.G./329/11.
8 *See* Vol. XI, Part II, Chap. V.
9 D.D.G. (C)/C.M.G./329/11.
10 *Ibid.* ; D.M.R.S./538.
11 Sec./Gen./2239.

in providing the Army with ammunition. They worked continuously throughout enemy air-raids to assemble rounds of anti-aircraft ammunition with the reduced charges required for barrage fire in the defence of London in September, 1917, and again to meet the urgent demands of British forces during the German advance of March, 1918.[1]

It was, however, during the period under consideration, viz., from August, 1914, to December, 1915, that the work of the Ordnance Factory in filling and completing ammunition was of primary importance. During this time, the rounds filled or completed for land service at Woolwich numbered 5,533,300 out of a total of 6,466,800, or roughly five-sixths of the whole. Moreover, during by far the greater part of this time, the Ordnance Factory had the sole responsibility in this respect. It was not until the third quarter of 1915 that filling by the trade began to account for any quantities of shell. Filling operations in the new National Filling Factories began only in the last quarter of 1915, and then in comparatively small quantities only. In the spring of 1916 these factories caught up and rapidly outpassed the Ordnance Factory. The latter continued to increase its output of filled shell for land service until a year later. From the third quarter of 1917 onwards its work in filling and completing shells for the Army gradually diminished. The proportion of its work in this respect to that of the national factories and the trade was entirely reversed. The aggregate number of rounds filled and completed for land service at Woolwich from August, 1914, until the end of the war was 43,322,300, against a total of 196,014,700 from all home sources, or rather more than one-fifth of the whole.[2]

III. Shell-filling by the Trade.

The utilisation of trade resources for filling and assembling land service shell began with orders for complete 18-pdr. rounds placed in November, 1914.[3] Two of the armament firms, Messrs. Vickers and Messrs. Armstrong, Whitworth, then undertook to manufacture complete 18-pdr. rounds of shrapnel and high explosive shell, the cost of extensions for this purpose being borne by the War Department.[4] Deliveries under Vickers' contracts for complete rounds were due in March, 1915; but they were considerably delayed. Thus, by the end of October, 1915, 26,993 shrapnel rounds only had been delivered out of the million shrapnel and H.E. rounds then due from the firm.[5] Owing also to a misunderstanding on the part of the firm, the whole of their extensions at Dartford were devoted to completing shrapnel, and no part of them to the filling and completing

[1] Sec./Gen./2239; D.D.G. (C) 1 C.M.G./329/1; *see* Vol. X, Part VI, p. 44.
[2] *See* below, p. 79.
[3] Contracts/T./4920.
[4] (Vickers) Contracts/S./7497, Contracts/A/2901; (Armstrong, Whitworth) Contracts/Firms A./1797, Contracts S./7346.
[5] *Firms and Factories List*, October, 1915, p. 68.

of H.E. rounds, throughout the year 1915.[1] On the other hand, Messrs. Armstrong, Whitworth's capacity for filling H.E. shell was expanded much more rapidly. This firm undertook to load all the H.E. shell for which it was contracting, receiving permission to sub-contract with the Thames Ammunition Works for some of the work[2] and to utilise for their 18-pdr. H.E. shells blocks pressed by the Explosives Loading Company.[3] The assembling factory, which was laid down by Messrs. Armstrong, Whitworth at Derwenthaugh, was sufficiently advanced to begin operations early in June, 1915. The filling factory for heavier natures of high explosive shell was built for melt-filling only at Lemington Point, about a mile and a half from the firm's Scotswood Factory, and output began there in September, 1915.[4]

While negotiations were in train with the two armament firms, it was realised that the existing filling capacity owned by Messrs. Armstrong, Whitworth would be entirely inadequate to cope with the immense increase in their H.E. shell orders. The remaining available capacity belonging to the Explosives Loading Company at Faversham was largely occupied on the Admiralty order for mine-filling. Accordingly, as a result of a conference between the contracts officer (Mr. Hanson) and representatives of the Explosives Loading Company and Nobel's Explosives Company, arrangements were made for the Explosives Loading Company to double its works at Faversham and to erect a new shell-filling factory adjacent to the T.N.T. works which Nobel's proposed building at Pembrey. The Faversham extension was laid out for lighter natures and included plant for pressing 18-pdr. block charges. The War Department bore 90 per cent. of the cost and the works were to become the firm's property after the war, arrangements being made for their maintenance in case of any subsequent national emergency.[5] The plant was ready by the end of April, 1915, a month later than the contract term; but output was not affected by this constructional delay as no empty shells came forward in the meantime.[6] The factory at Pembrey was laid out for heavier natures. Construction began on 18 April, 1915, and actual filling on 2 July following.[7] The factory was taken over by the Ministry from January, 1917.

In January, 1915, the War Office was still faced with great difficulty in arranging filling capacity for the large number of Q.F. H.E. shell, for which orders had been placed.[8] Without making any allowance for additional ammunition demanded on 12 December, 1914, and expected in the following June, the requirements of both services for filling H.E. shell, as formulated on 31 January, 1915, fell considerably below the capacity for which arrangements were being made

[1] Contracts/A./2901.
[2] Contracts/S./7346.
[3] *Ibid.*
[4] Hist. Rec./R/1340/19.
[5] Contracts/Firms E./1189.
[6] 94/Firms E/10.
[7] Hist. Rec./R/1124/6.
[8] *Ordnance Board Annual Report*, 1915, p. 219.

at the Ordnance Factory and by the Explosives Loading Company and Messrs. Armstrong, Whitworth. The following table illustrates the position in regard to high explosive filling at this time.

Position in Regard to H.E. Filling, 31 January, 1915.[1]

1915.	Requirements.			Estimated Capacity.		
	Army.	Navy.[2]	Total.	O.F.	Trade.	Total.
February	464	986	1,450	200	250	450
March	1,084	407	1,491	200	450	650
April	1,084	337	1,421	800	1,000	1,800
May	1,330	550	1,880	1,000	1,250	2,250
June	1,064[3]	516	1,580[3]	800	1,000	1,800
July	1,330[3]	296	1,626[3]	1,000	1,250	2,250
Totals, Feb.–July ..	6,356[3]	3,092	9,448[3]	4,000	5,200	9,200

The above table shows the deficiency in filling capacity to have been mainly due to the demand for additional ammunition formulated by the Master-General of Ordnance on 12 December, 1914. Some difficulty in arranging extensions arose from the fact that the proportions of H.E. and shrapnel shell remained undecided. In January, 1915, in order to relieve the Ordnance Factory negotiations were initiated with the King's Norton Metal Company, a firm already engaged in filling minor components, to undertake the filling of H.E. shells. The War Department subsidised an extension for filling 4·5-in., 4·7-in. and 60-pdr. H.E. shells which was undertaken by the Company in their works at Abbey Wood.[4] The work of erection began in April, 1915, and part of the factory was ready to begin operations on 24 September, following. Output of filled 4·5-in. shell began under this agreement in October, 1915.

The adoption of 80/20 amatol as a filling for 18-pdr. shells in June, 1915, enabled use to be made of presses, which had originally been installed by Messrs Curtis's and Harvey at Faversham in connection with a project to adopt the French shell filling Schneiderite.[5] Owing to practical difficulties in the handling of shell at Faversham, the firm's work was restricted to the manufacture of block-charges to be filled into 18-pdr. shell at the Ordnance Factory.[6]

To summarise, the use of trade capacity for filling H.E. shell was limited at the outbreak of war to the loading of naval shell at Armstrong, Whitworth's Scotswood Factory. The Explosives Loading Company's existing works at Faversham were not utilised by the British Government until the Admiralty placed its orders for filling naval mines in

[1] Figures denote tons of H.E. to be filled.
[2] Inclusive of requirements for mines and torpedoes.
[3] Exclusive of the demand, 12 December, 1914.
[4] Contracts/S./8097.
[5] *See* Vol. X, Part IV, p. 14.
[6] Hist. Rec./H/1520/6, p. 8.

October, 1914. In November, 1914, arrangements were made with two of the armament firms to assemble and complete 18-pdr. shells of their own production. At the same time, Messrs. Armstrong, Whitworth undertook to build a new factory for loading H.E. shell. These arrangements took the form of assisted contracts, under which the War Department became responsible for the greater part of the capital expenditure. Similar agreements were made with the Explosives Loading Company to duplicate its filling plant at Faversham and to erect a factory for loading heavy natures at Pembrey. Negotiations with a firm, accustomed to filling minor components, were opened in January, 1915, in order to afford further relief to the Ordnance Factory. These resulted in the construction by the King's Norton Metal Company of a factory for loading medium H.E. shell, the capital expenditure being borne by the State.

These arrangements began to bear fruit with the first deliveries from the Explosives Loading Company's Faversham works in April, 1915. Their progress was delayed throughout the summer by difficulties experienced in training operatives, and rendering them familiar with the ordinary regulations for explosives factories.[1] It was not until the third quarter of the year that the output of complete ammunition from trade factories began in any considerable quantity. Their total deliveries during that quarter amounted to 199,500 rounds, or approximately one-seventh of the whole of the home output of ammunition.[2]

When the first difficulties had been overcome, the progress of the trade filling factories was rapid. Thus, the average output of 18-pdr. shrapnel rounds at Derwenthaugh increased from 4,000 to 35,400 per week between August and December, 1915, and the deliveries of the same nature from Dartford increased from 7,502 weekly in October to 17,250 weekly in December. Apart from the responsibility, which the filling firms undertook in regard to the new national factories,[3] they also took certain steps in the autumn of 1915 to extend their trade capacity. Thus, for instance, the Explosives Loading Company undertook in October, 1915, to increase its melt-plant for 40/60 amatol by 50 tons weekly.[4] During the last quarter of the year 1915 the proportion of the filling and completing operations performed by the trade increased considerably, and amounted to 660,400 rounds, or rather more than one-quarter of the whole of the home output. During the next quarter, i.e., the first quarter of 1916, the proportion of the responsibility for filling and completing ammunition, which was borne by the trade factories, reached its climax, amounting to very little less than one-third of the whole output from home sources. The actual work of the trade in filling and completing ammunition continued to increase until the autumn of 1916, reaching its climax in the third quarter of that year with an output of 2,709,500 rounds.

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[1] Cf. HIST. REC./R/1340/19.
[2] *Review of Munitions Output*, 1914–18, p. 52.
[3] *See* below, Chap. III.
[4] HIST. REC./H/1340/1, Chap. XI, p. 6.

These figures relate to the land service only. They were fairly maintained throughout the year 1917, but were considerably reduced in order to meet the reduction in the gun ammunition programme during 1918 and by reason of the development of more economical methods in the National Filling Factories.[1] The total output of gun ammunition for land service produced by the trade filling and assembling factories during the war amounted to 26,610,500 rounds.

A very large proportion of the filling work undertaken by contractors consisted in the filling of fuses and minor components. These were operations with which certain firms were already familiar at the outbreak of hostilities and the trade capacity was enormously expanded during the course of the war. The details of this important branch of filling are separately treated below.[2]

[1] *See* below, Chap. IV.
[2] *See* below, Chap. V.

CHAPTER III.

THE ESTABLISHMENT OF NATIONAL FILLING FACTORIES, 1915–1916.

By the time the Ministry of Munitions was formed, in June, 1915, the few firms which had had any experience in filling gun ammunition had undertaken extensions for this purpose, while very large increases had been made to the filling and assembling capacity of the Ordnance Factory.

I. The Inception of National Filling Factories.[1]

It was necessary to create entirely new factories to meet the large schemes for shell manufacture undertaken by the Ministry during the summer of 1915, and to complete American ammunition. These included (1) factories for filling and assembling Q.F. (quick-firing) ammunition and for making up B.L. (breech-loading) cartridges; (2) factories for filling heavy shell with high explosive, and (3) factories for filling fuses, gaines, and other components. Some further extensions were made to the Ordnance Factory and to trade undertakings as already described in the preceding chapter. The bulk of the new filling capacity was, however, created at national factories under various forms of management.[2]

The first of the National Filling Factories was projected in connection with the Leeds local munitions committee with a view to completing the shells to be manufactured within that area. Investigations towards fixing a site for a filling factory had already been undertaken by 17 July, 1915, when, with the appointment of Major Strange, the new Filling and Assembling Department of the Ministry began definite efforts to organise new capacity for completing ammunition. By this date arrangements had also been set on foot by Mr. West for the erection of a National Fuse-filling Factory at Coventry under the management of Messrs. White and Poppé, application having been made to the Minister for the necessary financial authority on 1 July, 1915.

(*a*) Erection of Four Factories for Q.F. Ammunition and B.L. Cartridges.

The Leeds factory was intended for filling and assembling Q.F. ammunition and for making up B.L. cartridges. Three other similar factories were immediately projected at Liverpool, Glasgow, and Gloucester. These localities were chosen with a view to their transport facilities and particularly the means of communicating with ports of shipment; although a project for establishing three factories at the ports of Devonport, Avonmouth, and Newhaven was abandoned.

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[1] Hist. Rec./H/1340/1, Chapters I.-V.

[2] For a summary account of each factory, *see* Vol. VIII, Part II, Chap. V.

Each one of the four factories was intended to handle shell produced by the local munitions committees and was managed by a board of directors nominated by the local committee and approved by the Minister. The Liverpool factory was also intended to complete the rounds of 18-pdr. ammunition which were about to arrive from America. In order to comply with safety conditions the buildings were widely spaced over an area estimated at 100 acres. Still larger sites were taken in order to allow for expansion. They ranged from 175 acres in the case of Liverpool to 308 acres at Gloucester. Construction began at Leeds and Glasgow (subsequently called Georgetown in honour of the Minister) upon 13 and 25 September, 1915, respectively, and at Liverpool and Gloucester on 18 and 20 October, 1915, respectively.

All four factories were to be designed on much the same plan. Each was to be capable of filling and assembling 80,000 rounds of 18-pdr. and 10,000 rounds of 4·5-in.-shell per week, of making up 200 tons of B.L. cartridges per week, and of filling 100,000 primers per week.[1] Each was built in four complete units, so that single units could begin work as soon as they were complete. The shells were to be filled with block-charges. The making up of B.L. cartridges involves a fire risk only and block-filling, until the shell is fused, is comparatively speaking a safe operation. These two operations were concentrated in a single group of factories in order to separate work of a less dangerous character and to carry out the more dangerous processes in certain factories only.

(*b*) Scheme for Five Shell-filling Factories.

It was thus arranged that the more dangerous operation of filling the high explosive bursting charge into heavy natures of shell should take place in factories distinct from those which were engaged in making up the B.L. cartridges.

A site was chosen for the first and largest of the factories at Chilwell, near Nottingham, by Lord Chetwynd, who was appointed in August, 1915, with full responsibility for the erection and operation of the factory. It was to be situated in the Midlands to intercept heavy shells on their way from the shell factories of the north and centre of the country to the port of embarkation. It was to be capable of dealing with 1,000 tons of pressed charges and 500 tons of melt weekly. Its establishment presented peculiar difficulties, since the method of filling had not then been determined. The site, which eventually covered some 208 acres, was acquired early in September, 1915, and construction began in the middle of that month.

During the autumn of 1915 three smaller national factories were projected for filling heavy shell. Two of these were to be laid out for 500 tons pressed and 200 tons melt charges weekly, and were to be managed by two of the armament firms, Messrs. Vickers and Messrs. Armstrong, Whitworth ; the third was designed for 300 tons of pressed or melt charges weekly and was to be controlled directly for the Ministry by a manager, Mr. J. B. McNamara. Messrs. Vickers were to erect

[1] The actual capacity of each factory was subsequently slightly varied.

the one factory near the National Projectile Factory which they were to construct and operate at Lancaster. This factory was to fill shells from these works and from others on the north-west coast: negotiations with the firm began early in August, 1915; but the site was not acquired until 6 November following, and building only began on 23 November. The factory was called "Morecambe" in order to distinguish it from the Lancaster National Projectile Factory. Messrs. Armstrong, Whitworth undertook the erection of the second factory near their works at Elswick. A site was chosen at Lemington within easy distance of Elswick and other shell factories on the north-east coast, and the factory was styled "Newburn" in order to distinguish it from the firm's works at Lemington Point. No constructional work had been begun by the end of the year and this factory was never completed.[1] Decision was taken to erect the third of these factories in September, 1915. It was intended as an emergency factory for filling 8-in. shell and also for pressing block-charges for 18-pdr. shell. Considerable difficulty was experienced in finding a suitable site in the desired locality, viz., the near neighbourhood of Leeds, Bradford, or Halifax, whence the empty shells were to be drawn. Projects for utilising an existing factory at Lightcliffe near Halifax or a site at Sandal Magna near Wakefield were abandoned in turn. Eventually some 294 acres were acquired at Otley, midway between Bradford and Leeds, on 13 November, 1915. The clearing of the site began at once, but no constructional work beyond the laying down of railway sidings had been put in hand by the end of the year and the factory was never completed.[2]

These four factories were intended to serve the northern districts. It was considered desirable to choose a southern site for a fifth factory, to resemble the emergency factory at Otley for dealing with both light and heavy shell up to 8 in. as required. It was to be designed to press 300 tons weekly. Considerable difficulty was again experienced in finding a suitable site. The choice eventually fell upon the Bushey Farm Lodge estate, at Watford, where labour and transport facilities were good and a large power station existed. The Explosives Loading Company undertook to manage the Watford factory, as a more desirable project than the extension of their own works at Faversham, where the labour supply was exhausted, the staff overworked, and the district exposed to air-raids. The land was, however, in the nature of a model farm, and upon closer survey in December, 1915, it was considered too limited for the lay-out under contemplation. The scheme was accordingly abandoned and was partly replaced by a project for building a factory for melt-filling with picric acid, of which a surplus supply then existed. The site for this factory was found at Banbury by Mr. Eve, an officer of the Office of Works, whose services had been lent to the Ministry. The land, consisting of 142 acres, was taken in December, 1915, and construction began on 28 January following. The factory was laid out and operated by a managing director under the direct control of the Department.

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[1] *See* below, p. 26.
[2] *See* below, p. 26.

(c) Factories for Filling and Completing Components.

Negotiations with Messrs. White and Poppé for erecting and managing a fuse-filling factory near their fuse factory at Coventry continued throughout July. The land was acquired and construction began by 12 September, 1915.

London was chosen as a convenient centre for the remaining factories for filling components, of which large quantities were being imported from overseas. The work was of a less dangerous nature than other filling operations and could therefore be carried on in more closely populated neighbourhoods, while the cost of transporting minor components of comparatively small size and weight was relatively little. Thus it was possible to make use of the advantages offered by the Metropolis in regard to labour and railway facilities. A proposal was considered for assembling at Newhaven the minor components for B.L. ammunition, which were being imported there in large numbers from France and Switzerland, and would be re-embarked there when completed. The Ordnance Stores had already absorbed all the labour in the neighbourhood and the scheme was accordingly abandoned.

The first London site chosen covered 120 acres at Park Royal (Perivale). It was inspected by the chief engineer of the Metropolitan Munitions Committee on 17 August, 1915, and the land was taken on 26 August. The factory was intended for filling 200,000 fuses, 200,000 gaines and 400,000 detonators weekly, and it afterwards undertook the filling of primers and tubes. It was erected and equipped by a sub-committee of the Metropolitan Munitions Committee and was at first operated by the same sub-committee. Construction began as soon as the site was acquired. The factory was laid out in three units, of which one was completed and the remainder approaching completion by the end of the year.

Investigation was made for further London sites by Mr. A. C. Blyth. A site covering some 60,000 square feet at Sumner Street, Southwark, was taken on 27 August, 1915. The land was unoccupied and its title in dispute. Labour was lent temporarily by the Oxo Company, whose original offer of the upper floors of an adjacent warehouse had been refused by reason of the danger involved. The factory was erected at great speed by Mr. Blyth and consisted chiefly of wooden buildings some of which were obtained ready made. Construction began on 1 September, 1915. The filling of gaines began ten days after the occupation of the site. Regular output began on 1 October and the factory was complete on 15 November. The factory was intended to handle all kinds of minor components and was laid out also for assembling 5,000 No. 100 fuses weekly. It was operated by Mr. Blyth acting as managing director under the direct control of the Department.

A site for a second emergency factory was chosen by Mr. Blyth at Hayes, about 11 miles from Paddington on the Slough line of the Great Western Railway. It was at first intended that a large factory for component filling should be erected upon this site, which covered 200 acres, and that the Southwark factory should be subsidiary to it. The two factories continued under Mr. Blyth's management throughout

the war. Construction began at Hayes on 18 September, 1915. The factory was originally laid out for assembling 100,000 fuses, 300,000 time rings, 200,000 primers, 300,000 T tubes, and for filling 50,000 18-pdr. shells with block-charges. On 3 November, 1915, a shell-filling section capable of filling 200 tons of amatol and 100 tons of picric acid weekly was planned along the lines of the Explosives Loading Company's factory at Pembrey to take the place of a part of the Watford scheme, then abandoned.

Two other national factories for minor components were erected and managed by two firms familiar with this kind of work. In August, 1915, the King's Norton Metal Company undertook to construct and operate a factory at Abbey Wood for filling 100,000 gaines, 200,000 fuse detonators, 200,000 T tubes, 200,000 primers, and 50/100 tons of cartridges weekly. Construction began on 23 September, 1915, and the whole of the factory was approaching completion by the end of the year. The project for the second factory, to be erected and managed by Nobel's Explosives Company, was discussed during August, 1915, and definitely adopted on 9 September. A site was chosen at Cardonald on the Glasgow and Paisley Joint Railway. Construction began on 18 October, and in spite of delays due to snow-storms was practically complete by the end of the year.

These six factories for filling minor components were primarily intended to supplement the capacity for this work, which had been found to be very defective in August, 1915, when the Ordnance Factories were transferred to the Ministry of Munitions.[1]

II. Construction and Equipment.[2]

With the exception of the five shell-filling factories, the new establishments planned in 1915 were of light construction and contained comparatively little plant or machinery. The majority of the building contracts were on a prime cost basis, with a percentage allowance for profit, and were arranged to some extent through the Office of Works. The building contractors were selected by the local board, the managing agent, or the manager appointed by the Ministry. In most cases preliminary negotiations had already been opened with contractors before the Office of Works was called into consultation. On 4 September, 1915, the Office of Works agreed to give assistance towards the building of the National Filling Factories by a method resembling that already in force in the case of the National Projectile Factories. Mr. Frank Baines, Principal Architect to H.M. Office of Works, undertook the general examination and criticism of plans for the factories, and controlled the experienced technical officers who were appointed to most of the factories by the Office.

Constructional work began at twelve National Filling Factories between 26 August, 1915, and the end of the year. In seven cases the building contract was placed on a cost plus percentage basis, which varied as to detail. The main terms of the contracts are shown in the table which follows :—

[1] *See* below, Chap. V.
[2] HIST. REC./H/1340/1, Chap. VI.

CONSTRUCTION OF THE FIRST NATIONAL FILLING FACTORIES, 1915.

Factory.	Date when Construction began.	Nature of Factory.	Authority responsible for Construction.	Building Contractor.	Nature of Contract.
Perivale	26 Aug., 1915	Fuse filling	Sub-Committee of Metropolitan Munitions Committee	Messrs. McAlpine & Sons	On a schedule of prices.
Southwark	1 Sept., 1915	Component filling	Mr. A. C. Blyth	——	——
Coventry	12 Sept., 1915	Fuse filling	Messrs. White & Poppé	Mr. John Gray, of Coventry	On a schedule of prices; penalty for delay and bonus for early completion.
Leeds	13 Sept., 1915	Q.F. Assembling	Local Board of Management	Messrs. W. Irwin & Co., Leeds.	Prime cost plus 10 per cent. to cover establishment charges, building tools and plant.
Chilwell	15 Sept., 1915	Shell filling	Lord Chetwynd	Messrs. Holland & Hannen & Cubitts.	Prime cost plus 7½ per cent. on all charges.
Hayes	18 Sept., 1915	Component and shell filling.	Mr. A. C. Blyth	Messrs. Higgs & Hill, Ltd., S. Lambeth Road, London.	Prime cost plus 10 per cent. on labour and materials and 5 per cent. for establishment charges; prime cost plus 7½ per cent. for shell-filling section.
Abbey Wood	23 Sept., 1915	Component filling	King's Norton Metal Co.	King's Norton Metal Co.	Lump sum.
Georgetown	25 Sept., 1915	Q.F. Assembling (later, shell-filling)	Local Board of Management	Messrs. McAlpine & Sons, of Clydebank.	Whole cost of every kind plus 1 per cent.
Liverpool	18 Oct., 1915	Q.F. Assembling	Local Board of Management	Bullen Brothers	Lump sum contract (after competitive tender) plus additional work on a schedule of prices; bonus for early completion.
Cardonald	18 Oct., 1915	Component filling	Nobel's Explosives Co.	Messrs. McAlpine & Sons, of Clydebank.	Prime cost plus 2 per cent. on materials and workmen's compensation, and 7½ per cent. on all other items to cover establishment charges, tools and plant.
Gloucester	20 Oct., 1915	Q.F. Assembling	Local Board of Management	The Gloucester Constructionists, Ltd.	Prime cost plus 2 per cent. on materials and workmen's compensation and 7½ per cent. on all other items, to cover establishment charges, tools and plant.
Morecambe	23 Nov., 1915	Shell filling	Messrs. Vickers, Ltd.	Mitchell Bros., Ltd., Glasgow	Prime cost plus 7½ per cent. to cover establishment charges.

The most satisfactory of the prime cost contracts were those arranged at Gloucester and Cardonald with the assistance of the Office of Works. In these, a very considerable difference was made between the contractors' profit upon purely constructional services, and upon the material supplied. In several cases, independent action already taken by the authority in charge of construction with a view to expediting work led to a less favourable basis of payment. Thus negotiations with the building contractor for Chilwell had been begun before the arrangement made for general supervision by Mr. Baines, and prolonged discussion of the contract resulted in a settlement considerably less favourable than those for Gloucester and Cardonald. Similar difficulties were experienced in regard to Morecambe and Hayes. Most of the building contracts, except those for Hayes and Leeds, contained some clause relating to bad materials. In the case of Liverpool, defects due to bad workmanship were to be made good at the contractor's expense within a fixed period. Good quality was usually ensured by the fact that the authority for construction had special knowledge of the firms chosen, who were usually local builders.

Subsidiary work upon the provision of light, heat and water supply was undertaken by the Office of Works for all factories, except Southwark and Hayes. There was ample time to obtain competitive tenders for this class of work. The provision of sidings was carried out by the railways concerned at a fixed charge on cost.

Towards the end of October, 1915, a Director of Factory Construction was appointed to control the erection both of the National Projectile Factories and the National Filling Factories. It was, however, decided on 3 November, 1915, that the Office of Works should continue to supervise, independently of the Director of Construction, the work at filling factories, which were lighter in structure than the projectile factories and were built to contain far less machinery. The arrangements for supervision by architects and clerks of the works at each factory were not, however, put into full effect. Appointments were made to each factory with the exception of Hayes, where the managing director asserted his independence until the factory was practically complete. Nevertheless, individual directors were slow to recognise the dual responsibility owed by the local representatives of the Office of Works to the Department as well as to themselves. In one case, viz., at Chilwell, the managing director availed himself of Mr. Baines' aid in framing the builders' contract, and of the assistance of an architect and clerk of the works appointed by the Office of Works ; but he refused to recognise the subordination of these two officers to any but himself, thus limiting considerably the central supervision over expenditure to which Mr. Baines had trusted to counterbalance the terms of a somewhat unfavourable contract.

The equipment of the filling factories consisted of tools and plant of a special character. In the case of the shell-filling factories, where the methods of operation were as yet undecided, the exact nature of much of the equipment was still unsettled at the end of the year.

The experienced agents who undertook to build Abbey Wood, Morecambe, and Cardonald were responsible for providing plant and tools for those factories. Mr. Blyth provided those for Hayes, and Lord Chetwynd not only purchased but also designed a great part of the equipment for Chilwell. The equipment for the remaining six factories was designed by Mr. J. C. Aylan, who had had experience in the detail of filling processes as manager in charge of danger buildings at the Ordnance Factories, Woolwich. The outfit for these factories was then purchased through the Machine Tool Branch of the Gun Ammunition Department. Some idea of its extent and variety may be gained from the fact that the cost of equipping each factory varied from £50,000 to £100,000, and that the items supplied ranged from heavy hand presses to papier mâché trays and bronze thimbles.

III. Difficulties and Delays, 1915.[1]

The establishment of the new factories was undertaken under extremely adverse circumstances. The importance of organising capacity for filling and completing ammunition *pari passu* with the provision of new capacity for making the shell-case and the empty component does not appear to have been realised at the inception of the Ministry. It was not until late in July, 1915, that definite steps were taken to organise filling and assembling factories for completing the ammunition which was about to be produced under the new Ministry programmes. It was not until the end of August that the transfer of the Ordnance Factories to Ministry control revealed a very great deficiency in the arrangements made for filling and assembling fuses and minor components to balance the War Office programme.

Many of the operations concerned needed light buildings only and comparatively little plant ; but the relative facility with which these could be provided was heavily balanced by lack of experienced workers and by the entire absence of any body of trained experts in the commercial world, such as could be found in the engineering trade. In choosing the sites and laying out the plans for the new factories, very special conditions had to be observed in regard to the dangerous nature of the work. In starting up operations, theoretical knowledge had to be supplemented by familiarity with an enormous amount of purely technical detail. The headquarters staff, the management staff, and all the operatives of the factories needed training. This mostly took place at the Ordnance Factory. It was only in the case of the comparatively few agency factories that the factory staff could be drawn from, or aided by, the experienced management in contractors' works. So long as the Ordnance Factories were bearing practically the whole burden of completing gun ammunition for immediate issue, it was impracticable to withdraw from them any of their staff. Short courses for management staff and foremen were arranged in connection with the Ordnance College in August, 1915,

[1] Hist. Rec./H/1340/1, Chap. XII.

and those under training were permitted to visit the filling factories in the Royal Laboratory. Later, women overlookers were trained in large numbers at the Ordnance College, and by actual practice in the filling shops of the Ordnance Factory.[1]

The construction of the lighter factories for assembling Q.F. ammunition and filling components was well on the way to completion by the end of the year, and staff and labour were coming forward. The slight delays which had been experienced were due to general causes such as difficulty in getting constructional and engineering labour and in providing plant for heating and lighting. On the other hand, the erection of the shell-filling factories was very backward. Constructional work had only just begun at Morecambe It had not been started at Newburn or Banbury. At Otley, work had been confined to the railway sidings. Chilwell alone had made substantial progress. Yet these five factories were to be responsible for filling the enormous quantities of heavy shell which were shortly to be delivered from the new National Projectile Factories.[2]

(a) TECHNICAL DIFFICULTIES.

The delay at Otley was partly due to objections raised by the financial authorities to the prime cost tenders obtained for its construction. The main cause of the general delay in erecting this group of factories was alleged to be uncertainty as to the method of filling to be used, and hence as to the lay-out and equipment. It had at first been intended to erect these factories for block-filling with 80/20 amatol only; but the acceptance of the 80/20 mixture in larger natures was still in question and supplies of T.N.T. were expected to be sufficient to allow of the restriction of this mixture to smaller natures until 1917. It was therefore decided at a conference called by the Minister on 30 September, 1915, that the capacity of the shell-filling factories should be duplicated and sufficient melt plant erected to enable 40/60 amatol to be substituted for 80/20; yet, with the exception of Chilwell, progress with the melt-plant was as backward as with the press-plant at the end of the year. A British mission was sent to France to examine methods of filling in October, 1915. One section of the mission, led by Lord Chetwynd, reported in favour of pressing all charges direct into the shell from the nose. Lord Chetwynd erected experimental shops at Chilwell and developed a satisfactory method of pressing 80/20 into larger natures by mechanical means. It was not, however, until 25 January, 1916, that a definite decision was given to abandon block-filling by reason of the superior results obtained at trials of pressed charges in shells filled at Chilwell.[3] In addition to this uncertainty as to the general method of filling to be used, difficulties arose from ignorance as to the particular type of plant which would be best suited to the various operations. For example, the first method of incorporating 80/20 amatol had been worked out in gunpowder mills

[1] HIST. REC./H/1340/1, Chap. VII.
[2] Mr. Geddes to Mr. Lloyd George, 16/1/16 (C.R. 4436).
[3] *See* above, Chap. I.

owned by Messrs. Curtis's and Harvey; but it was by no means determined whether this was the best plant for the purpose or whether it would be easier to obtain a different class of machinery. Again the limits of the work to be undertaken in the filling factories remained to be fixed. Thus it was only decided after some discussion that the work of breaking down the ammonium nitrate and incorporating it with T.N.T. should be carried out at the filling factories in order to avoid the difficulty of transporting a hygroscopic mixture from the place of manufacture.[1]

(b) Administrative Difficulties.

These technical difficulties hampered the establishment of the shell-filling factories during the autumn of 1915. At the same time, the whole department for completing ammunition was passing through a series of administrative difficulties to cope with which it was ill-equipped. The effects of the shortage of technical staff increased with the rapid changes made in the design of ammunition during the winter. Lack of office accommodation and delays in providing the necessary organisation for estimating capacity against requirements or for keeping count of the available components and other essential stores tended to hamper the whole of the work at headquarters.[2]

The arrangements for completing ammunition were prevented from working smoothly by the lack of an adequate system for storing and allocating components or for proving and storing the completed rounds. During the summer of 1915, serious difficulties threatened from the congestion of the Ordnance Stores at Woolwich, where all components were received for issue to the Ordnance Factories or to contractors. It was calculated that the increased production of components to meet the Ministry programme would raise the quantity of stores and components to be moved from factory to factory to at least one million tons yearly. The arrival of unfused and incomplete ammunition from America in 1915 added a new factor to the problem. Large storage accommodation was built, adapted and equipped at Plymouth and Devonport, to receive ammunition as it arrived and to fuse and complete it. The burden of arranging a system for circulating stores between factory and factory rested with the department controlling the filling factories.[3] At the end of August, 1915, it was agreed that the Ordnance Stores should supply only the Ordnance Factories and certain riverside works, while the Ministry should make its own arrangements for storing and circulating components for trade factories as well as for the new National Filling Factories. The first store was set up at Birmingham early in September, and a system of circulating was developed and accepted a month later. The provision of storage advanced rapidly to meet the growing output of components

[1] C.R. 4435.
[2] C.R. 4436.
[3] *See* above, Chap. I.

and to supply accommodation for such articles as ammunition boxes. for which alone 6,000,000 cubic feet were needed in December, 1915.[1]

It was essential to build up a stock of components for the filling factories as they came into operation and the provision of storage for them was an urgent matter. The congestion of filled ammunition awaiting proof was a difficulty likely to increase later as the new output began. The Ministry itself undertook the preliminary work of establishing proof ranges to supplement those at Shoeburyness and so to avoid congestion of unproved shells at filling factories.

Among all these administrative difficulties the greatest probably arose from the severance of responsibility for the new filling capacity and for the Royal Laboratory, which was then completing by far the greatest part of the ammunition made. The disadvantages of this arrangement were very clearly illustrated by misunderstandings as to the supply of textiles, for which reliance was at first placed upon the Ordnance Factory, with the result that practically no supply of silk-cloth for cartridge-bags was forthcoming in January, 1916.[2]

IV. Reorganisation under Mr. Geddes, January–July, 1916.

The administrative changes made by Mr. Geddes when he took responsibility for the filling and assembling of gun ammunition as well as for the control of the Ordnance Factory have already been described.[3] Their main purpose was to lessen the time-lag between the manufacture of shell components and the completion of the round. At the same time the staff of the Department was strengthened by a reorganisation of duties, and the addition of experienced, administrative and technical officers. The filling programme was carefully revised and efforts were made to strengthen its weak places.

(a) Revision of the Original Scheme for Shell-filling Factories.[4]

Decision was given by the Director-General of Design on 25 January, 1916, that filling of 80/20 amatol should be by the French method of stemming and pressing, and that the mixture should be made by the process evolved at Chilwell. It was, however, considered desirable to proceed with the duplicate melt-plants at the new factories, since the construction and equipment of the more complex press-units would occupy a much longer period. The 500-ton melt-unit at Chilwell was about to start up shortly; but additional melt capacity was essential at least to act as a stand-by in case of disaster at Chilwell.

Towards the end of December, 1915, it had been decided that Newburn and Otley should deal with 18-pdr. to 4·5-in. shells instead of the heavier natures for which they had originally been intended. They were to have press and melt units, the latter being capable of ready conversion for filling larger natures in case of emergency. In mid-January, however, little progress had been made with either

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[1] Hist. Rec./H/1340/1, Chap. IX.
[2] *See* below, Chap. V.
[3] *See* above, Chap. I.
[4] Hist. Rec./H/1340/3.

factory.[1] Orders were then given to enable work to proceed, pending the settlement as to methods of filling; but it was finally decided at a conference with the Minister on 17 February, that these two projects should be modified. Newburn, the site of which was much exposed to enemy aircraft, was abandoned, and a substitute was provided by adding to Georgetown. It was at first intended to proceed with the erection of the Otley factory, but it was finally decided to transfer its administration to the Leeds Board of Management, and to erect it on a site adjacent to the assembling factory at Leeds, in order to facilitate the Board's control.[2] A similar policy was also applied to the Liverpool Assembling Factory, to which it was decided, in February, 1916, to add a shell-filling unit for small natures capable of mixing and stemming 250 tons of amatol weekly. Thus, in order to obtain the advantages of unity of control, a definite departure was made from the original policy of separating assembling from shell-filling factories in order to distribute danger risks. It was not considered desirable to carry out the new policy to the full by erecting a shell-filling unit near the Gloucester Assembling Factory since labour and transport facilities would not have been adequate there.

(*b*) Inception of a Stand-by Factory at Hereford.

The construction of the shell-filling units at Georgetown, Leeds, and Liverpool began early in March, 1916. About the same time the arrangements for filling were reviewed as a whole and decision was taken to insure against the destruction of either Chilwell or Morecambe. For this purpose the Minister sanctioned the erection of an additional factory to fill 700 tons of amatol weekly (20 March, 1916). A site was found at Hereford, and construction began on 10 June, 1916. On 12 June the lay-out was slightly modified. The capacity of Morecambe was then extended from 500 to 700 tons weekly, of which 400 tons were to be pressed and 300 tons melt; simultaneously the capacity at Hereford was reduced to 400-tons melt-plant to fill 40/60 amatol and 100 tons melt-plant for picric acid.

Hereford was intended as a stand-by filling factory in the event of the greatest possible single catastrophe, *i.e.*, the destruction of the press-plant at Chilwell. In that event it was intended to fill all 18-pdr. shell with block-charges from a reserve which was gradually raised to three million charges from the output of the two trade makers, the Explosives Loading Company and Messrs. Curtis's and Harvey. The 18-pdr. press plant at the national factories would thus be available in an emergency for filling larger natures and the filling of the remainder of the heavy shell could be undertaken at Hereford.

V. The Starting-up of the National Filling Factories.[3]

No effort was spared between January and July, 1916, to bring the new National Factories into full operation. The progress of construction was greatly advanced by the administrative changes made by

[1] C.R. 4436. [2] C.R./Filling/26.

[3] Hist. Rec./H/1340/3, Chap. IV; *Review of Munitions Output* (1914–1918), pp. 54–59.

Mr. Geddes in January, 1916, and building was hastened by a special temporary section under a Director of Constructional Progress.

Operations had already begun in some of the emergency and component-filling factories. At Southwark regular output started with gaine-filling on 1 October, 1915; at Hayes with the block-filling of 18-pdr. shells on 30 October, 1915. The completion of American 18-pdr. shrapnel had also been undertaken at the Devonport depôt during the last quarter of that year. Together, Hayes and Devonport had completed or assembled 73,600 rounds of 18-pdr. ammunition by the end of the year. The output of filled components began from Perivale on 1 December, 1915, and from Abbey Wood and Cardonald during January, 1916. Last of all, the national factory at Coventry, whose construction had been considerably delayed throughout the winter, started filling graze fuses in March, 1916, and the erection of a second unit for time and percussion fuses was begun about the same time.

With the exception of the 73,600 rounds from Hayes and Devonport no complete ammunition was delivered by the national factories before January, 1916. The four national factories for assembling shell and making up cartridges came into action during the early months of 1916. Leeds, the first of these factories to be planned, led the way with certain experimental work in December, 1915, and began small-scale output *pari passu* with Liverpool and Georgetown towards the end of January, 1916. Leeds and Georgetown completed certain quantities of foreign ammunition during the first quarter of that year. Output from the fourth factory, Gloucester, began in March. The four factories were well started by the end of April, and their three new shell-filling units, beginning with Leeds on 18 April, were all working by July, 1916.

The decision given towards the end of January, 1916, in favour of stemming and pressing H.E. charges into the heavier natures removed the main cause of delay in setting up the shell-filling factories for larger natures. Chilwell was well in advance, owing partly to its construction for this method as well as for melt-filling, in anticipation of formal authority. Trial shells were filled at this factory in January, 1916; regular output began there during the following month, and entire reliance was placed upon its output of heavier natures for the summer campaign. In spite of the late date at which construction began, the comparative simplicity of laying-out melt-plant for filling with picric acid enabled Banbury to start filling shell towards the end of April, 1916. The construction of Morecambe was hastened during the spring, but its output did not begin to supplement that from Chilwell until the third quarter of the year. Hereford, the last of the shell-filling factories to be projected, began filling with picric acid in November, 1916.

Although the National Filling Factories had by no means reached full output during the second quarter of 1916, they were then producing ammunition in quantities which exceeded the output from the Ordnance Factory. As the later national factories began operations and the work at all of them expanded, the proportion of their output more than counter balanced that of the Ordnance Factories and the trade

together. Thus the issues of gun ammunition from the national factories amounted to ·5 of the aggregate home output in the third quarter of 1916, and to ·7 in the fourth quarter. Throughout the war these factories continued to complete quantities of ammunition largely in excess of those handled by the Ordnance Factories and the trade. In spite of the comparatively late date at which they came into operation their total output during the period of the war was ·6 of the whole amount which was filled and completed between August, 1914, and December, 1918.

VI. The Cost of the National Filling Factories.

No attempt was made, when the National Filling Factories were first planned, to obtain more than a rough estimate of the cost of each. Without delaying to obtain detailed estimates, it was roughly calculated in September, 1915, that the entire outlay, including the cost of land, would be under £2,250,000. The four assembling factories were estimated at £120,000 each, the four shell-filling factories at £150,000 each. Chilwell was to cost £632,000. Three of the component factories (Hayes, Perivale and Coventry) were expected to cost about £150,000 each. The estimates for the remaining three factories of this group—Abbey Wood, Cardonald, and Southwark—were respectively £15,000, £30,000, and £1,000.[1]

Owing partly to the rough character of these estimates, partly to unanticipated extensions and alterations, and partly to the building of entirely new units such as Hereford, the ultimate cost of the National Filling Factories far exceeded the outlay of £2,208,000 expected in September, 1915. The total capital expenditure amounted by March, 1918, to more than ten and a quarter millions, which was made up of the following items[2] :—

	£	s.	d.
Abbey Wood	116,405	16	0
Banbury	173,973	9	10
Cardonald	63,521	3	2
Chilwell	2,712,097	19	3
Coventry	813,400	10	10
Georgetown	1,368,356	4	7
Gloucester	410,451	13	3
Hayes	899,085	7	9
Hereford	1,281,327	6	4
Leeds	813,475	0	0
Liverpool	725,419	12	2
Morecambe	199,894	7	9
Pembrey	102,254	19	4
Perivale	522,808	6	0
Southwark	41,113	11	3
Total	£10,243,585	7	6

This total excludes the expenditure upon factories which were erected at a later date under the control of the Gun Ammunition Filling Department, but for special purposes, and also the cost of converting plant to purposes other than that of filling H.E. and shrapnel shell or their components.

[1] Hist. Rec./H/1340/1, Chap. VI, p. 1.

[2] Hist. Rec./R/400/57.

CHAPTER IV.

ADMINISTRATIVE PROBLEMS IN COMPLETING AMMUNITION, 1916–1918.

Practically all of the new factories for completing gun ammunition which were established under the Ministry of Munitions were in operation by the summer of 1916. The single important exception was the Hereford Filling Factory which had been planned at a late date and was intended mainly as a stand-by plant. Output in bulk was rapidly attained when once the factories had started work; but the organisation and maintenance of filling upon an enormously increased scale called for an administration which should be both courageous and careful. Wise forethought, detailed planning, and concentrated research went to ensure the safety and efficiency of the factories and to balance the interests of output with those of economy. During the next nine months the output and efficiency of the factories engaged upon completing gun ammunition advanced steadily. From 1917 to 1918, with the reduction in the gun ammunition programme, the class of work which was undertaken varied considerably, but similar methods were applied to its execution.

I. Industrial Management.

The management of filling factories presented certain very special difficulties. Work was invariably carried on "in an atmosphere of actual danger, some (often considerable) discontent among the workers, of constant anxiety owing to uncertainty of the synchronization in supply of components and of changes in the nature and actual pattern of the articles to be supplied."[1] The danger risks attached to handling explosives necessitated the maintenance of an unusually strict factory discipline. The conditions of work seriously affected both the recruiting of the workers and their general treatment.

(*a*) Discipline in the Filling Factories.[2]

The handling of all classes of explosives under an enormous variety of conditions involved danger risks which were almost inestimable. A great deal of the work which was undertaken in filling factories, *e.g.*, charging with amatol, was entirely new and but little guidance could be gained by previous experience. The quantities of ammunition which were handled were immense, so that the risks of, at least, ten years' work under peace conditions were encountered in two to three months

[1] C.R./Filling/347.

[2] Based, so far as danger building practice is concerned, upon a memorandum by Colonel Sir Hilaro Barlow (Hist. Rec./R/1122.3/59).

during the whole of the two and a half years in which the National Filling Factories were in operation. The urgency of a large and immediate output was daily present in the minds of managements and operatives; while only the comparatively rare occurrence of any serious accident in an operation safely repeated a million times or more brought home to all concerned the daily need for unceasing care. The health and safety of individual workers and of the whole factory depended upon the constant observance of numerous minute regulations. The danger arising from carelessness was on a par with the risk of malicious damage. It was as important that operations in filling factories should be effected under conditions which minimised the possibility of accident as that the ammunition itself should be "fool-proof." The "special conditions of scrupulous cleanliness in working, avoidance of force, the frequent inability to employ the most expeditious mechanical devices on account of danger, and in some cases having to forbid any hurry, are extremely distasteful to Managements" . . . "The vast majority of operatives never have accepted, and never will accept, the restrictions imposed as really necessary."[1] For example, "operatives have a perfect genius for the improper use of tools" and hence definite measures to prevent the presence of tools unsuitable for use in a certain class of work were essential. In such respects the discipline in the filling factories approached a military standard. The rules issued for the national factories, and later for trade filling factories also, regulated the personal behaviour of the workers in minute detail. They called for implicit obedience to every order, before a complaint was made, however great the worker's grievance might be. Absolute obedience was, however, difficult to enforce when other kinds of work were easy to obtain. No accident in filling factories was ever definitely traced to malice; but the workers themselves suffered numerous small injuries through failure to use the precautions prescribed, while carelessness and lack of discipline in a single factory were the cause of numerous prematures and failures among ammunition issued in 1916, and for three full months in the winter of 1916–17 prevented the production of any serviceable output.[2]

On the other hand, it was undesirable to give rise to any nervousness in place of the regular habit of mind, which should make the observance of danger-building conditions a normal rule of every-day life. Moreover, insistence upon any one of the risks involved in this class of work was apt to cause panic and increase the difficulty experienced in recruiting labour for work which was already sufficiently distasteful. Thus, while the operatives in filling factories showed great courage and persistence in returning to work after several appalling disasters, recruitment of labour and regularity of attendance suffered considerably as a result of a general panic in regard to T.N.T. poisoning during the later months of 1916.[3] Workers absented themselves from work as the result of slight accidents in a degree which varied with local

[1] HIST. REC./R/1122·3/59, pp. 1–2.
[2] D.D.G. (C)/C.M.G./251.
[3] *Ibid.*

temperament and was quite incalculable.[1] From the first the Department regulated safety conditions in the National Filling Factories, in accordance with the terms of the Explosives Act of 1875. After the Silvertown explosion in January, 1917, powers were taken to make regulations to secure the safety of any place where explosives were made or handled, and the Department's rules could accordingly be applied to trade filling factories.[2] The administrative arrangements which were made to ensure conditions of safety in accordance with the development of experience applied both to the manufacture and use of explosives, and have already been described in the account of explosives supply.[3] Owing to the comparatively large numbers of operatives employed in the filling and assembling factories, the drafting and observance of danger-building regulations were matters of special importance in this class of work.

In the autumn of 1915 a staff of danger-building officers was organised for each of the new filling factories. They reported to an expert adviser on danger-building practice, Colonel Sir Hilaro Barlow, formerly a superintendent of the Royal Laboratory, who also watched the construction of the filling factories from the point of view of safety precautions. The danger-building officers had no previous knowledge of the special conditions in filling factories. They were military officers who received a short training in their duties at the Ordnance College at Woolwich and in the Royal Laboratory. The system was effective in that there were remarkably few accidents during the anxious period between March and August, 1916, when the factories were learning their work. There was, however, considerable friction between the managements and the danger-building officers, and in August, 1916, the latter were placed under the authority of the management, who thus became responsible for the safety of the factory as well as for its output and efficiency.[4] Advice and independent criticism as to danger-building practice were also given by the technical inspectors of the Department when they visited the factories. Books of regulations were issued to the national factories from headquarters from time to time and, as has been seen, these regulations were applied to trade filling factories handling T.N.T. after January, 1917.

Many circumstances militated against an entirely perfect danger-building practice. The factories were laid out and constructed by several independent managements, most of whom had an elementary knowledge only of the precautions to be taken. For the sake of speed in building and operation the lay-out often departed considerably from the regulations which would have been enforced in time of peace. Thus, for instance much inflammable material was used in constructing the factories, a circumstance which in at least one instance (at Morecambe) aggravated a fire which destroyed the whole factory in October,

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[1] C.R./Filling/347.

[2] Vol. II, Part I, Chap. VI.

[3] Vol. X, Part IV, pp. 120–126.

[4] D.D.G. (C)/C.M.G./284/5, 360.

1917[1]. Similarly the closer spacing of buildings, intended for economy in erection and speed in operation, intensified the effects of any disaster. Moreover, when the filling factories were first planned little was known of the properties of some of the explosives to be handled. Thus, the very large loss of life arising from an explosion, which destroyed the amatol-mixing plant at Chilwell in July, 1918, was largely due to the fact that fire, rather than explosion, had been feared from amatol, when the factory was built, and that the lay-out accordingly exposed many workers to the effects of explosion. Certain preventive measures were almost outside the bounds of possibility. For instance, by about March, 1916, the non-inflammable and flash-resisting clothing normally supplied to all operatives was practically unprocurable, and the cost of fireproofing cotton materials which were then substituted became quite prohibitive and their use was eventually abandoned.

The managements slowly grew to appreciate the importance of a closely regulated danger practice, with experience and the development of their responsibility for safety conditions, although accidents due to insufficient insistence as to methods of work occurred as late as 1918. Right up to the end of the war, the workers' independence of control and the great difficulty which was experienced in obtaining men and women of good quality for subordinate managing posts, prevented conditions in the new factories from reaching the standards of perfection laid down for well-managed factories in peace-time. Nevertheless, it was far from the case that work was carried on in an unnecessarily dangerous way. British ideals were not always reached; but the practice in British factories far excelled that of other countries.

(b) LABOUR IN THE FILLING FACTORIES.

The use of mechanical contrivances in filling and completing shells was strictly limited by considerations of safety. A very large proportion of the work done consisted in the constant repetition of the same operation by hand, and with minute care and an exact regard for detail. From the very outset the majority of the workers in the National Filling Factories were unskilled women whose only training was a short probationary period in the workshops. They were drawn at first from the ranks of women workers of all classes, domestic servants, dressmakers, milliners, clerical workers, and dairy-maids. Towards the end of 1916, when the fear of T.N.T. poisoning was at its height and labour for the increased gun ammunition programme was difficult to obtain, a special appeal was made to women of independent means. The total number of men and women employed in National Filling Factories rose steadily from 28,710 in July, 1916, to 70,280 in July, 1918. They formed the largest single class of employés under the direct control of the Ministry outside the Royal Ordnance Factories.[2] Considerable difficulty was experienced in getting operatives to do work which entailed the handling of T.N.T., tetryl, or certain other

[1] C.R.V./Gen./0455.
[2] Vol. VI, Part IV, p. 62.

explosives. Quite apart from the dangers involved the nature of the work was often extremely distasteful, and the precautions required, such as the wearing of respirators in handling fulminate of mercury compositions or the smearing of the face with special grease in handling tetryl, were peculiarly irksome.[1]

The active intervention of the Ministry in regard to the " welfare " of munition workers was largely based upon the peculiar conditions needed to ensure the health and well-being of operatives in the filling factories. The measures which were taken to provide food and recreation, and the efforts of the Department to lessen or remedy the effects of T.N.T. poisoning have been described in detail elsewhere.[2] It should, however, be noted here that one of the main measures introduced, viz., the alternation of labour, hampered output considerably and caused discontent among the workers on other processes who were put on to T.N.T. work in order to relieve the regular T.N.T. workers. Special rates of payment in excess of local rates were allowed to " shell-fillers " in view of the dangers of their work,[3] and it was only the high wages which workers obtained on bonus or on special rates which made it possible to maintain a supply of labour where T.N.T. or tetryl was handled in large quantities.[4] The whole question of methods of payment was reviewed in December, 1916, when it had been suggested that recent prematures were the result of careless work arising from the bonus system or other methods involving piecework payment.[5] In individual factories various methods had been adopted during 1915 and 1916 with a view to obtaining the good output arising from piecework without giving rise to careless work. Thus, for example, in one fuse-filling factory, payment was based on a fixed rate per hour plus a bonus on output, the bonus being withheld when the quality of the work fell below a certain standard. A " fellowship " system operated throughout another factory. Each girl in a group was responsible for a single operation only, and passed back any defective work received from her predecessor; payment was made on an assumed normal output; novices went straight into a group so that it was to the interest of each group that its new-comers should work well and quickly.[6] In January, 1917, it was definitely laid down that any bonus scheme which did not contemplate a limit on output was undesirable since there was obviously a time factor for performing each operation, below which work could not be done with intelligence and safety. Thenceforward no proposals to introduce schemes for bonus or piecework were considered unless they provided for a limited output per worker or per shop.[7]

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[1] C.R./Filling/347.
[2] Vol. V, Part III.
[3] D.D.G. (C) 251.
[4] C.R./Filling/347.
[5] D.D.G. (C)/C.M.G./251.
[6] *Ibid.*
[7] *Ibid.*/276/1.

II. Improvements in Efficiency.

As the new filling factories started up during the summer of 1916, the quantities of gun ammunition which were completed increased enormously; but its quality left a great deal to be desired. Blinds and prematures which occurred during this year were ascribed to various causes which have already been stated.[1] There was no doubt, however, that many defects were due to inexperience and carelessness in the assembling of components and in methods of filling generally.

The essential importance of every small operation in completing gun ammunition was emphasised by the comparatively minute causes which led to blinds or prematures. A careful investigation of one store only, the gaine, disclosed the fact that detonators had been inserted upside down, and that gaines had been filled with two detonators, or none, or had been loaded with insufficient tetryl. The year 1917 began with six months' trouble with the No. 44 fuse, of which rejections for blinds were the rule. In the spring of 1917 there came a wave of prematures with the time and percussion fuse which was in largest demand, the No. 80.[2] It was only by concentrated investigation into the causes of each class of defects, by careful control over the details of factory practice, and by the general tightening up of methods of inspection, that the quality of the ammunition was gradually improved. By the end of 1917, the results of proofs, themselves carried out by new and reliable methods, showed that all ammunition had attained a uniformly high standard of quality.[3] Considerable care was thenceforward needed to maintain this standard, and to provide for the alterations in pattern which still arose from changes in military conditions or from the growing need for economy.

(a) Technical Advances.

The most remarkable developments in the technique of filling were advances which were made in the methods of loading shell with amatol. Experimental work at Chilwell, and later at other national factories, and investigations by technical experts, particularly Dr. T. Martin Lowry, D.Sc., F.R.S., of Guy's Hospital Medical School, and Dr. A. F. Joseph, all combined to this end. This gradual advance in knowledge and methods was marked by several especially noteworthy steps. The experimental work done, under Lord Chetwynd, at Chilwell during the winter of 1915–16 established the practicability of stemming and pressing heavy natures of shell with cold 80/20 amatol. A method of hot-filling with this mixture was evolved at Georgetown towards the end of July, 1916; and when at length approval of this process was given in the following December, the buildings containing the melt-plants at many of the new factories were thereby enabled to turn over to some extent to the use of the more economical 80/20 mixture in place of amatol 40/60. Another class of research was intended

[1] Vol. X, Part IV, p. 17.
[2] Hist. Rec./R/1320/10, p. 9.
[3] M.C. 372.

to replace hand-labour by automatic contrivances so far as was consistent with the interests of safety. For this purpose screw-stemming machines were evolved at Chilwell and Liverpool for cold 80/20 amatol in the spring of 1917, and similar machines were shortly afterwards introduced for filling with hot amatol.[1]

The investigations carried out under the aegis of the Gun Ammunition Filling Department were set out in detail in a series of reports on the properties and treatment of amatol and ammonium nitrate, upon trotyl exploders, and upon methods of test and analysis.[2] The methods evolved at the National Filling Factories with the experimental work undertaken at the several factories formed the subject-matter of a second series of technical reports.[3] The work of the technical section of the Department, which had been established by Mr. Geddes in the spring of 1916, expanded enormously as the new factories started up and opportunity arose for studying factory practice and watching experiments on a factory scale.

The work of the technical section included a close examination of empty components in order to prevent rejections after filling, careful examination of filling methods and of designs for the same purpose, measures to secure changes in design in order to economise labour and material, changes in the standard of inspection to facilitate the use of serviceable material and a comparison of all processes with a view to saving labour, money and materials. By the end of October, 1917, the section had obtained 19 changes in design to economise steel, brass, or copper, 25 to economise timber, 6 to economise textiles, and 10 to save labour.[4] A very important part of its investigations related to the design of fuses and other components.[5] The troubles experienced with fuses No. 44 and No. 80 in the early part of 1917 were largely remedied by changes in design. Research was also concentrated in the spring of 1917 upon the Mark III primer, which was then brought into supply as a means of economising labour and materials, but gave as many as 14 per cent. rejections at proof. Three months' work upon the pattern of this component proved the superiority of the new Mark from the point of view of efficiency as well as of economy. The cost of material per 1,000 was reduced from 115*s*. 3*d*. to 75*s*. 6*d*., the cost of filling from 50*s*. to 20*s*. The design of components and the customary methods of filling them were systematically reviewed with the object of eliminating unnecessary items which had often been originally introduced for a purpose which was since obsolete and forgotten. The elimination of two small items, a paper collar and a cardboard disc, alone effected a yearly saving of £15,000 while improving rather than damaging the quality of the ammunition.

Rejections of the 1·7-grain detonator were very high in May and June of 1917. For a single week in this period 25 per cent. of an

[1] HIST. REC./H/1520/8.
[2] *Ibid.*/R./1520/7.
[3] *Ibid.*/R./1340/25.
[4] C.R./Filling/347.
[5] HIST. REC./R/263·37/14 ; 1320/10.

output of 1,171,000 were rejected. Systematic comparison of the machines, methods and materials used, and careful supervision on the part of factory managements so improved the quality of this store by the end of September, 1917, that the rejections were reduced to 12 per cent. of an output of 1,637,000 weekly, and at one factory where they had previously amounted to 48 per cent. of the output, they were reduced to 4 per cent. only.[1]

These improvements were the more remarkable since the standard of inspection had been raised in the meantime. Wherever it was possible, machinery was substituted for hand-work. The reduction in the cost of filling primers was mainly due to the fact that the new Mark could be filled automatically. Cartons of tetryl, which could be filled by machinery, were substituted for a certain proportion of the batiste exploder bags in order to lessen the danger to health through unnecessary handling of this explosive. The change was not applied to all exploders, since large stocks of batiste still existed in January, 1918. At the same time, an effort was made to save labour and money by dispensing with both the bag and the carton and pressing the explosive directly into the metal exploder container, which had been brought into supply during the year 1916.

A central experimental unit was established at the Perivale Filling Factory in August, 1917, for the purpose of producing components under ideal conditions, and of studying methods for filling and assembling components for use throughout the factories. The unit was known as the Standard Production Establishment since one of its main objects was to test the value of methods in use in different component factories and to secure the general adoption of the most efficient and economical.[2]

(*b*) IMPROVEMENTS IN PRACTICE.

It is impossible to estimate how much of the general improvement in the quality of the ammunition was due to increased skill among the rank and file of the workers. The new filling factories started up in the summer of 1916 with labour which was utterly lacking in experience. The foremen and forewomen had received a very brief instruction at the Ordnance Factory; but they formed a very small proportion of the 40,000 operatives who were engaged in filling and assembling ammunition in the national factories by the end of the year. Even though the operations to be performed were comparatively simple, great exactitude was required of the workers and some time necessarily elapsed before they attained the facility which comes only from much practice. The training of so many novices was, moreover, hampered by changes in design which constantly altered the routine of their work. It was not unnatural, therefore, that many of the defects in the ammunition issued during 1916 were due to bad workmanship, to bad fuse assembly, dirty fuse detonators, bad filling of gaines and defective gaine detonators.

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[1] C.R./Filling/437;.
[2] HIST. REC./R/1320/10.

Improvements in practice came with experience and with close supervision of the detailed work of each national factory. As capacity increased, it also became possible to insist upon improvements in the quality of trade output, and in one instance a contract for 1·7-grain detonators was cancelled in view of bad workmanship and the dirty conditions under which filling took place.[1] Towards the end of 1917 it became customary to break down locally a certain percentage of each factory's output of fuses, gaines, detonators, etc., so that the management and operatives might gain direct instruction from their own faults.[2]

(c) THE TIGHTENING UP OF INSPECTION.

The inspection of filling and assembling took place at the filling factories themselves during operations. Examiners were stationed in the various units and watched some half-dozen operations. They thus picked up any defect while work was continuing and in many instances the fault was rectified at once under skilled supervision. Samples of the amatol mixed in filling factories were taken twice daily for analysis. A check examination was made of a certain percentage of the completed ammunition and samples were taken for proof. Certain filled components, such as detonators, underwent very special and critical examination before issue to filling factories. Materials, *e.g.*, textiles, were examined at two central stations in London and Leeds. During the course of the war, the work of examination and testing was much complicated by the introduction of new methods of filling, and by multifarious changes in the nature of the small components and materials which were used.[3]

During the year 1916 the standards of inspection were raised considerably as a means of rectifying the general defects in the quality of the ammunition then produced. With the aid of the Home Office chemists Messrs. Dupres, a specification was drawn up for the 6·6·4 mixture for use in detonators, which had previously varied considerably in quality, and a standard form of test was evolved.[4] Lack of uniformity in the standards of inspection gave rise to serious difficulties in regard to certain filled components. During the early part of 1917 friction arose between operatives and inspectors in regard to the standard set for exploders, since the sentencing of this store then depended largely upon the personal opinion of the inspecting officer. As the result of a series of experiments a method of testing exploders by filled weight and length was introduced which satisfactorily eliminated the personal factor in sentencing these stores and secured a marked improvement in their quality.[5]

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[1] HIST. REC./R/1320/10.
[2] *Ibid.*, 263·37/14.
[3] *Ibid.*/H/900/7.
[4] *Ibid.*/R/263·37/14.
[5] *Ibid.*; D.D.G. (C)/C.M.G./239/1.

III. Financial Problems.

During the summer of 1916 the increase and maintenance of output continued to be the main consideration. Towards the end of the year, however, it became possible to give greater weight to interests of economy. Trade prices were reduced in December, 1916, and allocations to the filling factories were grounded in part upon comparative costs of production. Processes were altered and machinery was introduced with a view to saving labour. Designs were changed and accounting systems were reorganised in order to save material and place a check upon its use. The work of the National Filling Factories was closely studied as a means of gaining information on economy. Such methods were common to practically all the activities of munition supply during the last two years of the war. The peculiar conditions which applied to the handling of explosives placed very definite limits to the extent of their adoption, where the filling and assembling of gun ammunition were concerned.

(*a*) Economies in Methods and Materials.[1]

Very large economies were effected by the changes in factory practice and filling designs which were introduced as a result of the investigations of the technical sections, and have just been described. In particular, the introduction of machinery for filling shells, exploders, primers, and other components effected large economies during the year 1917. In some cases the use of automatic devices enabled work to be concentrated in fewer factories, with considerable financial saving.

The general administration of the national factories was gradually reviewed with regard to economy. Towards the end of 1916 there was a tendency to introduce bonus systems and many filling factories had adopted some form of payment by result by the following October, although the exact form of the bonus was strictly limited by the conditions already described.[2] It was considered that this partial adoption of bonus payments was one cause of an all-round reduction in the cost of filling operations in the national factories, which took place during 1917, in spite of a rise of 150 per cent. in the wages of females, and of over 100 per cent. in the wages of male operatives. The changes which were introduced in the minor details of completing ammunition also saved considerable sums. Thus it was estimated that the abolition of soldering in packing H.E. fuses saved £2,400 weekly. A general study of factory conditions led also to the salvage and re-use of all kinds of packages. Waste of the explosive during filling operations was more difficult to prevent, owing to the dangers inherent in the re-use of powders with which extraneous substances might be mixed.

A system of costing for filling operations had been laid down for the national factories from the date of their first operation.[3] During the

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[1] C.R./Filling/347.
[2] *See* above, p. 33.
[3] Hist. Rec./R/400/14.

summer of 1916, its application to all factories was restricted by the primary importance of output, the independence of many of the factory managements, changes in process and diversity of lay-out.[1] At the close of the fighting season closer attention was paid to comparative costs and already, in December, 1916, the knowledge thus gained in national factories was of considerable use in negotiating reductions of the trade prices for shell-filling.[2] The methods of accounting in filling factories were revised in May, 1917. The whole system of costing in filling factories was very closely interwoven with the general methods adopted by the Ministry in accounting for components and materials. Its systematic and uniform adoption was much hampered by the fact that issues to the filling factories were "free" and that considerable difficulty was at first experienced in obtaining prompt and accurate information as to the price of materials and components. The means which were used for reorganising the Ministry's accounts during the years 1917 and 1918 have been described in detail elsewhere.[3] Lists were issued of standard prices, at which the various materials and components were to be charged in calculating filling costs. Delays in obtaining the necessary information for these lists considerably hampered the development of the costing system. Great difficulty was also experienced in finding a unit of cost, which would admit of satisfactory comparison between the factories, in which methods and conditions were extremely varied.[4] These difficulties were gradually overcome, and by the close of the war the accuracy of the system of cost returns was well proved by close agreement between the expenditure as costed and as shown by the production accounts of each factory.[5]

The costs of filling and assembling shell in the national factories was considerably lower than the corresponding costs in trade factories. On the other hand, the filling costs for minor components were considerably greater than trade prices. This fact was in part due to the superior lay-out of the trade factories for this work, of which the firms concerned had an almost unique experience.[6] The difference was chiefly attributed to large on-costs at the National Filling Factories, where expenditure upon welfare and canteen arrangements was particularly heavy. It was also suggested that in these classes of work, such as detonator filling, it was to the interests of the firms to continue manufacture, even at a loss, with a view to maintaining their position in the post-war industrial market.[7]

Remarkable reductions were made in the contract prices for shell-filling and assembling towards the end of 1916, and at intervals from that date onwards. During the previous year, very considerable difficulty had been experienced in settling reasonable prices to cover

[1] C.R./Filling/88 ; 347.
[2] D.D.G. (C)/C.M.G/276/1.
[3] Vol. III, Part I.
[4] D.D.G. (C)/C.M.G./276/1.
[5] Controller of Factory Audit and Costs Balance Sheet for National Factories for the year ending 31 March, 1919.
[6] D.D.G. (C)/C.M.G./276/1 (Finance Committee Meeting, 18/10/17).
[7] C.R./Filling/347.

the work of filling and assembling, which was undertaken by the less experienced firms, such as the King's Norton Metal Company. Large discrepancies also appeared between the costs as estimated by the Ordnance Factory and by the few firms who had had any experience; while owing to the novelty of certain of the processes, no precedent existed in many cases.[1] The prices for much of the trade filling were not finally fixed until the summer of 1916, when a comparatively high charge was generally accepted as operating until March, 1916. Provision was made for a reduced price for deliveries during the remainder of that year, and for subsequent and much more drastic reductions. Thus, for example, the King's Norton Metal Company was allowed a price for filling 4·5-in. shells which included 120 per cent. on-cost on productive labour to the end of March, 1916. From that date onwards, 25 per cent. was charged to this item, subject to an investigation of the firm's actual costs.[2] Comparison between the costs at national factories and in trade works went far towards reducing trade prices from December, 1916, onwards. The contracts placed with Messrs. Vickers for completing and assembling 18-pdr. ammunition form a noteworthy instance. The retrospective price originally asked by the firm in June, 1916, was about double the cost of similar operations in the national factories, although the State had borne the greater part of the cost of extensions for this purpose. This considerable charge (£11 16*s*. per 100) was accepted as to the end of May, 1916, with a reduced price (£6 7*s*. per 100) until the following November. In December, 1916, a further reduction was negotiated in view of an undertaking that a rate of output should not be asked which would involve overtime or Sunday labour. The firm saw no advantage in coming in under the Ministry's scheme for indemnification against third-party risks, since a great part of the work at their filling factories was undertaken either for the Admiralty or for Foreign Governments. The price agreed in December was slightly below the average cost for similar work in National Filling Factories; but it obtained until the spring of 1918, when the firm asked for increases of practically 100 per cent., representing that the previous prices were insufficient to cover establishment charges and depreciation, and allowing very considerable sums towards insurance. The output from this contract was then essential to the fulfilment of the 18-pdr. programme. Accordingly arrangements were made to investigate the firm's costs and to bring its factories under the Ministry's scheme for indemnification against third-party risks. The firm's investigated costs were almost double those at national factories, being £10 9*s*. 7*d*. or £9 16*s*. 7*d*. for completing and assembling H.E. or shrapnel rounds against the corresponding figures of £5 17*s*. 4*d*. or £5 4*s*. 3*d*. at the national factories. The ultimate contract price was still under negotiation at the close of hostilities. Since the firm's prices on other contracts had been fixed on the basis of their investigated costs, it was considered that the same principle should apply in this case. A slight reduction was, however, made in the amount of profit allowed. The price finally

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[1] 94/S./8097. [2] C.R./Filling/88.

agreed along these lines in October, 1919, was £11 5*s*. or £10 11*s*. per 100, somewhat less than those asked in the spring of 1918.[1]

(*b*) THE LIMITATIONS OF ECONOMY IN FILLING.[2]

The extent to which economies could be adopted in filling factories was subject to very definite limitations. Economical methods were sometimes checked by the essential characteristics of the work, sometimes by less permanent conditions. The distasteful and dangerous nature of the work necessitated comparatively high wages in order to attract labour. · Compliance with safety precautions increased the spacing between shops and, in consequence, augmented the cost of handling and the maintenance of roadways and tracks. The need for maintaining a heavy insurance against the destruction of factories by fire or explosion involved large initial outlays upon spare capacity, such as the national factory at Hereford, in addition to upkeep. It was essential to keep together the labour which had been trained for the special work undertaken in filling factories. At the same time, filling operations were peculiarly subject to the general fluctuations in the gun ammunition programme which arose from the exigencies of the military situation. Work was slowed down each winter in order to avoid undue storage of filled shell. The filling factories were also subject to constant checks arising from suspicions as to the quality of the ammunition, since the first onus of prematures or blinds tended to fall on the final operations of manufacture. They were liable to be held up also by any fault in the constant flow of numerous components.

At the outbreak of war, filling with amatol was unknown in Great Britain. Throughout the war, the filling of a large proportion of H.E. shell was accordingly a highly experimental business carried out by means of empirical processes. The factories, which were built pending the development of efficient and economical processes, were distinguished by a great variety in plant and methods which did not allow of standardisation and rendered particularly difficult any attempt at comparative costing as a means of ensuring the economical allocation of work. In common with every other branch of munition supply, the economical working of the filling factories was hampered by frequent changes in design, even when these were introduced with a view to the ultimate saving of money or labour. About one-half of the special capacity which had been built up for filling gaines during 1915–16 was laid idle by the introduction of a new fuse (No. 106) which required no gaine. The substitution of a ·303 percussion primer for the T tube saved spare gun parts and tubes, but it also involved the abandonment of capacity for filling 500,000 tubes weekly.

During the years 1917–18 much administrative ingenuity was employed in adapting idle filling capacity for purposes other than that of completing gun ammunition. Within the limits of the peculiar conditions attaching to this class of work, allocations were made to the factories where a particular operation could be most economically performed.

[1] Contracts/A./2901. [2] C.R./Filling/347.

IV. The Allocation of Work, 1917–1918.[1]

During the summer of 1916 the whole of the filling capacity which was being developed was brought into operation at the first opportunity and special efforts were made to speed up the filling of heavy shell for the summer campaign. By October, 1916, it was clear that the capacity already projected would suffice for the gun ammunition programme as then planned; but the supply of H.E. fuses and gaines was a limiting factor in output during the next four or five months. This was partly due to grave suspicions cast upon the quality of the fuse and gaine filling at the Coventry National Filling Factory, partly to trouble experienced with the handling of tetryl, and partly to the defects in the design of the No. 44 fuse, already narrated.[2] During the winter of 1916–17 a further difficulty arose from a change over to cordite instead of nitro-cellulose powder in B.L. cartridges. Filling with cordite involved extra labour and skill, particularly in the case of cordite R.D.B. In consequence there was a marked discrepancy between the numbers of shells and cartridges which were accumulated.

In February, 1917, the lack of transport and storage facilities in France began to make themselves felt in the programme for completing ammunition. For a short time it was decided to concentrate upon the filling of cartridges and the general balancing of components rather than to continue the effort to fill shell to the utmost capacity of the factories. From December, 1916, onwards entire reliance had been placed upon the supplementary melt-plant of the new H.E. filling factories to provide a margin of safety in the estimated rate of filling. This margin would not in itself have been effective, since enough T.N.T. was not available to keep the melt-plant fully employed in the filling with 40/60 amatol. The margin accordingly depended upon the success of the new methods of filling with 80/20 amatol by the hot-mixed process, for which the buildings containing the melt-plant might be used to some extent. The Georgetown process for hot-filling was formally approved in December, 1916, and steps were taken to introduce it at Hayes, Leeds, Hereford, and the Ordnance Factory in the following spring. At the same time, the introduction of filling machines considerably increased the country's shell-filling capacity.

By March, 1917, the close study of component filling[3] and these improvements in the methods of shell-filling were bearing good fruit, so that the proved filling capacity of the country was considerably in excess of the estimated programme of empty shell and component deliveries, as then restricted by the tonnage problem and the general limitation in steel supplies. A definite reduction in the filling programme was accordingly made in April, 1917. A large proportion of the filling capacity was devoted during the following summer to the completion of 6-in. howitzer shells. By a special effort during the second week of August, 1917, an output of over 500,000 of this nature was attained in a single week.

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[1] D.D.G. (C)/C.M.G./219.

[2] *See* above, p. 34.

[3] *See* above, p. 35.

During this summer, the ultimate utilisation of the filling capacity which would be released by the reduction in the gun ammunition programme was under constant consideration. Already in May, 1917, shell-filling had ceased entirely at the National Filling Factory, Pembrey, which was thenceforward employed in breaking down defective ammunition. A reduction in land service allocations to the filling factories at Woolwich was projected in July, 1917, in order to free capacity there for naval filling. A certain amount of naval mine filling was also undertaken by the National Filling Factories, *e.g.*, Banbury was engaged in charging mines with an ammonium perchlorate mixture from September, 1917, onwards. In November, the Gun Ammunition Filling Department undertook to construct and operate for the Admiralty a national factory at Gainsborough, which was entirely devoted to the filling of special concrete sinkers. This factory began operations in the following February.

The advantageous position of the filling estimates was entirely reversed by the total destruction of the Morecambe Filling Factory early in October, 1917.[1] It was at first considered essential that this factory should be rebuilt in order to provide sufficient filling capacity for the 1918 programme.[2] Increasing tonnage difficulties led, however, to further reductions in the gun ammunition programme and the reconstruction of Morecambe was eventually abandoned in the spring of 1918, save for a small portion of the factory which was rebuilt for certain operations in poison gas filling.

The programme for filling was seriously affected during the winter of 1917–18, not only by the restricted tonnage position but also by the increased activity of hostile aircraft. Early in November, 1917, decision taken against accumulating large ammunition dumps in France led to a reconsideration of the filling programme with a view to reducing stocks. Work at the factories had already been considerably hampered by air-raids. Thus, for instance, nearly 70,000 working hours had been lost from this cause in three of the south-eastern filling factories during the period between mid-September and mid-October, 1917.[3] In January, 1918, it was proposed to take advantage of the general reduction in the gun ammunition programme by closing down the factories in the south-eastern district, which were most seriously affected by air-raids. After considering the problem from the point of view of labour supply, inspection, and finance, the Controller of Gun Ammunition Filling set out a scheme for running the national factories in the London area on day-shifts only and for entirely closing the comparatively costly factory at Abbey Wood which was within the air-raid district. It was also intended thus to reduce the explosives stored in the Woolwich magazines from which Abbey Wood was fed, and a simultaneous cut of three-eighths of the filling allocation to the Woolwich filling factories was proposed for the same purpose. Such a reduction was, however, opposed by the

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[1] C.R./Filling/347.
[2] M.C./351.
[3] C.R./Filling/347.

Chief Superintendent of Ordnance Factories on the ground of the large consequent discharges, which he estimated at 8,000, and the difficulty which would be experienced in providing alternative work for T.N.T. operatives if the picric acid sections were closed down.[1] The scheme involved the cancellation of a considerable number of filling contracts. The manufacture and filling of amatol 80/20 block-charges by the trade was to cease in favour of the cheaper and more efficient method of pressing at the national factories; but Messrs. Armstrong, Whitworth were to accumulate a certain reserve of lyddite 18-pdr. blocks upon closing down their Derwenthaugh factory, where they were filling and assembling 18-pdr. with lyddite. Other contracts for filling with 40/60 amatol and picric acid were to be cancelled in view of decisions to discontinue the use of picric acid as a means of economising sodium nitrate and to reduce the quantities of T.N.T. used to the minimum. Certain contracts for filling components necessarily terminated with these shell-filling orders. One or two others were to be cancelled in view of high charges or unsatisfactory quality.

The scheme was approved generally by the Council Member concerned on 16 March, 1918. Night-shifts and Sunday work were at once eliminated from all factories working upon fuses, cartridges and other minor components, but were retained in the shell-filling factories which were charging with amatol by a continuous process. The allocations to plant for filling with picric acid were rapidly reduced during the spring of 1918, and the whole of the picric acid section at the Hereford Filling Factory was closed in April.

In the same month certain of the gun ammunition factories began filling aerial bombs, for which there was an increased demand beyond the capacity of the Trench Warfare Filling Factories. The loading of aerial bombs had at first been undertaken in the Royal Laboratory and, to a small extent, by the trade. From August, 1916, onwards it had gradually been diverted from Woolwich to the Trench Warfare Filling Factories.[2] Arrangements were also made in the spring of 1918 for the utilization of spare capacity in certain of the Gun Ammunition Filling Factories for filling and assembling trench mortar ammunition. These arrangements were facilitated by the transfer of responsibility for trench warfare filling to the Gun Ammunition Filling Department, which took effect as from 6 May, 1918. The picric acid units of the National Filling Factories, which were closed down in accordance with the decision to restrict the use of this explosive, were converted to various purposes in connection with inserting the bursting charge into chemical shell and assembling Q.F. chemical shell with their cartridges.[3] In addition, an entirely new national factory was erected at Chittening for handling shell filled with the mustard gas, which was to be manufactured at the neighbouring explosives factory at Avonmouth. The operations which were undertaken at Chittening included the charging of the gas into the shell

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[1] M.C. 515.
[2] *See* Vol. XII, Part II, pp. 27–28.
[3] D.D.G. (C.)/C.M.G./219/2.

as well as the insertion of the bursting charge and the final completion of the round. The factory began operations in June, 1918, and throughout the summer much of the attention of the technical and supply officers of the Gun Ammunition Filling Department was diverted to the new and difficult problems involved in the handling of chemicals and explosives at the same factories.[1]

On 1 July, 1918, a severe explosion in the amatol-mixing section of the Chilwell Filling Factory completely destroyed the mixing house, T.N.T. mill and other buildings. Pending the reconstruction of this part of the factory, all the capacity available was needed in order to maintain the rate of shell-filling. The melt section of the factory resumed work at once, recourse was had to picric acid filling by contractors, and by dint of working longer hours the Trench Warfare Filling Factories undertook once more the work on bomb-filling which had been diverted to the Gun Ammunition Filling Factories. The position was the more critical, since an epidemic of influenza was seriously depleting the numbers of operatives, the wastage of labour was becoming particularly heavy in filling factories, and the distasteful nature of the work hampered recruitment.[2]

Upon the conclusion of hostilities, practically all filling ceased except at Woolwich Arsenal and certain trade factories, engaged mainly upon fuse-filling. The labour was at first diverted to stock-taking and clearing up, and by the end of the year 83 per cent. of the operatives had been discharged from the National Filling Factories. Certain of the factories were, however, diverted to breaking down ammunition and recovering the component parts.[3]

[1] *See* Vol. XI, Part II.
[2] (Printed) *Weekly Report*, No. 149, VI, A. (6/7/16).
[3] *Ibid.* No. 170, VI, A. (30.11.18); No. 173, I (28/12/18).

CHAPTER V.

THE SUPPLY OF COMPONENTS AND MISCELLANEOUS MATERIALS.

I. Introduction.

It is almost impossible to over-estimate the part occupied by the production of components in the general supply of gun ammunition. Manufacture of the empty shell in quantities sufficient for the demands of the new armies involved the organisation of the whole of the country's engineering capacity and appealed alike to public imagination and to administrative ingenuity. The provision of explosives and the organisation for filling and assembling the ammunition were factors whose importance could not fail to be recognised. On the other hand, an intimate technical knowledge of the difficulties besetting the provision of fuses, cartridge cases and other similar components was almost essential to a just appreciation of their value in the final production of the complete round.

In the early months of the war, the fact that the Ordnance Factory was the sole authority for filling, and for a large proportion of the assembling, of gun ammunition facilitated the organisation of component supply. The Chief Superintendent of Ordnance Factories drew from the Deputy Director of Ordnance Stores such items as, for instance, detonators or primers of trade manufacture. The provision of adequate quantities was thus a matter of factory management concentrated in a single authority who was intimate with every change in programme or design, actual or prospective.

As the work of completing rounds was undertaken first by the armament firms and trade factories and later by the new national factories, this centralisation of responsibility ceased to be effective. By the end of July, 1915, the capacity for filling components at the Ordnance Factory was declared to be insufficient to balance the new shell orders which were being placed by the Ministry of Munitions. In August, 1915, it became apparent that existing arrangements were insufficient even for the previous War Office programme.[1] Some steps were taken towards organising component supply and providing for the circulation of stores to the new trade and national factories during the autumn of 1915.[2] These measures were, however, in no way commensurate with the size of the problem. Moreover, the severance of design from supply which attended the formation of the

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[1] *See* below, p. 69.
[2] *See* above, p. 5.

Ministry deprived the supply authority of that foreknowledge which had enabled the Chief Superintendent of Ordnance Factories to exercise judgment in providing for the future balancing of his manufacturing programme.

Difficulties which attended the development of the detonating system for 18-pdr. H.E. shells brought the matter to a crisis at the end of 1915. While the new design authority within the Ministry was hastening the development of the graze fuse and the gaine, the procedure for completing gun ammunition was being entirely reorganised by Mr. Geddes, mainly with a view to correlating the production of every component in the complete round, The balancing of components is a problem of great complexity, in which the allocation of particular classes of fuses to particular types of shell, the use or disuse of a gaine, primer, tube, or other component, and numerous similar conditions are all subject to unforeseen change. In January, 1916, Mr. Geddes made a systematic investigation into the relation between the forecasts of component production and the final programme for the issue of gun ammunition.[1] Thenceforward, the balancing of components was recognised as the key to every estimate of gun ammunition supply. It cannot be said that the supply of any one component never, thenceforward, held up the Ministry's programme of gun ammunition manufacture. There must always be one or more limiting factors in output, and it frequently occurred that the supply of fuses, gaines, or other components held back ammunition supply. Such delays, however, no longer arose from lack of study or foresight ; they were the inevitable result of the peculiar difficulties which attend the production of these particular stores.

II. Fuse Manufacture.

(*a*) Development of Fuses during the War.

Gun ammunition fuses are of two kinds, percussion fuses designed to act on impact, and time and percussion (T. and P.) fuses, which are primarily intended to act after certain periods of time or, secondarily, on impact. Occasionally the percussion mechanism is omitted from time fuses. Generally speaking, percussion fuses are used with H.E. shells for destroying ships, buildings, or any kind of material, and time fuses with shrapnel shell against *personnel;* but no hard-and-fast rule can be laid down as to the method of employment, which varies with the military position and the usage of different nations.

The chief percussion fuses in use at the outbreak of war were the direct action fuses, Nos. 17 and 44, which are placed in the nose of the shell and act upon impact on the target when a weak needle disc or pellet is crushed in. With developments in the use of high explosive shell and the need for providing ammunition for wire-cutting, a fuse was needed to act on graze. Such a fuse can be either in the nose or the base of the shell and acts when the shell is checked. The No. 44

[1] *See* above, p. 5.

fuse had just been developed in the summer of 1914 as a means of bringing smaller natures of shells to detonation. The first 18-pdr. H.E. shells issued for wire-cutting during the autumn of 1914 were fused with a combination of a time fuse (No. 80) over No. 44 acting as a gaine, and this system remained in use as the only substitute for a graze fuse until June, 1915, when graze fuse No. 100 with a gaine began to come into supply. This graze fuse was of a pattern which had been approved on 29 December, 1914, but altered as to detail during the early months of 1915. During the summer of 1915, considerable defects appeared in the double fuse 80/44, in fuse 44, and, a little later, in the No. 100 fuse, of which issues began during the first week of August. Until February, 1916, the whole system of detonation for the smaller natures of H.E. shell was under consideration. Various changes were made in the pattern of the gaine[1] and the graze fuse itself was entirely re-designed. In order to maintain output pending the change-over to the new graze fuse (No. 101), arrangements were made to produce two modifications of the No. 100 fuse, which were called Nos. 102 and 103. The unsatisfactory quality of these 100-type fuses and the high percentage of blinds from the No. 44 fuse led to the introduction of an entirely new pattern, the No. 106.[2] In the No. 100-type graze fuse, action takes place upon the meeting of a needle and fuse detonator, one of which is inserted in a loose graze pellet, which moves forward on check. The graze pellet is usually kept in position by some form of detent, which is only released by the centrifugal force developed by the spin of the shell. In No. 106, the possibility of premature detonation was reduced to a minimum by an entirely different form of action. The needle was attached to a hammer projecting from the nose of the fuse, and protected for transit purposes by a cap removed before firing, and the hammer was secured by a brass tape which was unwound by the spin of the shell. The hammer was then only held by a shearing wire which was broken when the hammer was driven in by the impact of the shell. Authority was given to replace No. 100-type fuse by No. 106 in a large proportion of the medium shell and to adopt it in certain heavy natures between August and November, 1916;[3] but there was considerable delay before the new fuse was produced in large numbers.

The principal time and percussion fuse, No. 80, was a well-established pattern when war broke out. From the summer of 1915 onwards there developed a growing demand for a fuse which should burn for longer than 22 seconds, the time taken by the No. 80 fuse. The No. 83, a fuse of similar pattern, was designed to burn for 30 seconds. These types proved inefficient with the long-range guns. A new long-burning type, the No. 88, was developed in response to urgent requests received from France in February, 1916, and was approved in September, 1916. Serious difficulties were encountered in blending the materials to obtain a powder which would burn regularly in the time-rings of these fuses. A slow-burning composition was eventually evolved by the

[1] *See* below, p. 64.
[2] HIST. REC./R/800/2.
[3] D.D.G. (A.) 18067.

Research Department, Woolwich, where large quantities were also produced. In August, 1917, investigations were set on foot with a view to reproducing clockwork fuses, which had been in use among the Germans for some time. These mechanical fuses had great advantages over those which depended upon a slow-burning composition, since they functioned more accurately and after a longer period of time. and because they were not affected by weather conditions. The experimental stages of British production had passed by September, 1918, but production was limited to comparatively small quantities issued for trials only.

(*b*) EXPANSION OF FUSE CAPACITY, AUGUST, 1914–JUNE, 1915.

In August, 1914, the manufacture of fuses was undertaken only by the Ordnance Factories, Woolwich, and by four of the five great armament firms. The production of fuses had been a matter of special difficulty during the South African War, when the supply from the trade had failed almost entirely.[1] At the beginning of November, 1914, the first direct contracts for fuses were signed with the Raleigh Cycle Company and the Sterling Telephone and Electric Company, firms which had formerly acted as sub-contractors to the armament firms. From this time a gradually increasing number of orders were placed with private firms, many of which had previously been engaged on work of a totally different nature. Brass works generally, motor and cycle works, and firms manufacturing lamps and fittings appeared to be particularly adaptable for fuse production, but after some time practically every type of engineering and tool-making firm was to be found among the fuse contractors.[2] As the process of turning over existing plant or of making necessary extensions involved a considerable expenditure which could not always be met by firms otherwise well fitted for fuse manufacture, from October, 1914, advances were made for the erection of plant which should remain at the disposal of the Government during the war, although in most cases it remained the property of the firm concerned.[3] By the spring of 1915 about twelve British firms had taken contracts for fuses, while orders were also being placed in Canada and America. In May, offers of fuses were made by Swiss companies, but the War Office maintained its policy of leaving capacity in that country at the disposal of the French munition contractors[4] and limited itself to the development of British and American sources. In spite of the work done in this respect the shortage of fuses still prevailed. Repeated delays in deliveries from the armament firms were reported to be due to railway congestion which prevented the delivery of tools, the failure of metal contractors to keep their promises, and to labour difficulties.[5] The new trade firms met with unexpected obstacles in starting up, and in some cases were unable to procure small parts

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[1] HIST. REC./R/1122.11/19.
[2] *Firms and Factories List.*
[3] 94/F./1267.
[4] 94/F./108, 196.
[5] 94/F./21.

from sub-contractors,[1] with the result that deliveries bore little relation to orders and estimates. The situation was further aggravated by a large delivery of unfused shell from Canada in place of the complete rounds expected and additional fuse orders had to be placed to complete these shell.[2]

(c) Introduction of New Sources under the Ministry.

On the formation of the Ministry in June, 1915, the position demanded immediate action. So serious were the problems involved that in spite of the steps taken by the Ministry to increase production, the fuse output continued until June, 1916, to be a limiting factor of alarming dimensions in the issue of 18-pdr., 13-pdr., and 4·5-in. shell.[3] In June, 1915, further orders were placed with additional trade firms, and some railway companies undertook manufacture on a considerable scale[4] but various difficulties, particularly those in connection with design, prevented these measures from attaining their full value for some time. The policy of making assisted contracts was continued,[5] and American orders were steadily increased until by the end of March, 1916, they provided for nearly half of the total requirements. In the autumn of 1915 many of the National Shell Factories and co-operative groups were fully organised, and large orders for fuses were placed with Boards of Management and local committees. Nearly all of these were for graze fuses, while the older types of percussion and time fuses were obtained from direct contracts with British firms and from America. Considerable delay occurred, however, in starting up, for although most of the contracts placed through area organisations were signed by August or September, 1915, only very small deliveries were made before 1916.[6] Thus in November, 1915, when the groups held contracts for approximately 175,000 fuses weekly and deliveries had in most cases been promised before the end of October, the actual weekly output was some 5,000.[7] In August, 1915, the weekly deliveries of fuses were between two and three thousand less than the corresponding output of shell, and for some months the total output remained inadequate, although during the latter half of 1915 time or percussion fuses were not rigidly allocated to different kinds of shell, and a deficiency in supplies of the one could be made up from the other.[8]

By December, 1915, out of the 892,300 percussion and 587,700 time fuses delivered weekly, 883,800 and 575,200 respectively were produced by various firms, and it was considered that the chief business of the Ordnance Factory was to meet emergency demands.

On 21 December, 1916, it was decided to centralise the production of components for the National Projectile Factories by the erection of

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[1] 94/F./4.
[2] Hist. Rec./R/1320/1.
[3] *Ibid.*/R/1000/29.
[4] 94/F/190 A.
[5] 94/F/1267.
[6] Hist. Rec./R/1121/29.
[7] *Ibid.*/R/1121/29 and (Printed) *Weekly Report*, No. 18, I, (27.11.15).
[8] *Ibid.*/H/1300/1 and (Printed) *Weekly Reports*, September–December, 1915.

a National Components Factory at Tipton. The factory was originally erected by the Ministry between January and September, 1917, on land lent for the purpose by Messrs. Bean, who undertook to manage the factory for the production of shrapnel components, H.E. heads and nose bushes on plant transferred from the projectile factories. Almost from the first, however, the factory turned over to fuse manufacture.[1]

(d) Supplies from France and Switzerland.

Among the new sources utilised by the Ministry some of the most important were the French and Swiss contractors. In June, 1915, a plan was put forward by which the French were to organise Swiss production and supply the British Government after meeting their own requirements. While this scheme was under consideration a representative of the Raw Materials Department was sent over to investigate the possible sources of supply and found many Swiss firms well equipped for the manufacture of fuses and other small stores, although the metal supplies available in the country would barely last two months. Swiss capacity, however, was left to France until 7 July, 1915, when the French Government concluded that their own requirements could be met by the development of French production. In accordance with the final agreement between the two Governments, Great Britain undertook to accept the whole surplus production of H.E. fuses in France for the next six months, leaving to the French Government the entire responsibility for negotiating with manufacturers, and on this condition was left free to place direct orders in Switzerland in co-operation with the French representative.[2] Consent was obtained from the French Minister to the placing of direct contracts with two French firms, and in September a contract was signed with the Compagnie Générale d'Electricité for 1,000,000 fuses, the British representative in Switzerland acting also as agent to consult with the French Government. In November and December, 1917, large orders for fuses No. 80 and 106 were placed with two other French firms from which deliveries continued until November, 1918.[3] The total number of fuses obtained from French contracts was 10,500,000.[4]

As soon as the July agreement was made negotiations were immediately begun with Swiss firms in order that plant released by the completion of French contracts should not be used for German supplies. On July, 27, the British Ministry of Munitions representative was formally appointed with power to sign provisional contracts. British orders were placed with large firms which were permitted to subcontract with others in their neighbourhood, and by the end of August, 1915, Swiss work was well under way.[5] The first contract was

[1] C.S.M. 29758.
[2] Vol. II, Part VII.
[3] *Order and Supply Lists.*
[4] Vol. II, Part VII.
[5] Hist. Rec./H/1145/1.

signed on 18 August with M. Georges Favre, of the Fabriques des Montres Zenith at Le Locle, for 100,000 graze fuses weekly.[1] The following day the firm sub-contracted with Piccard Pictet et Cie, of Geneva for 48,000 of these, and from March, 1916, this latter firm also took direct contracts with the Ministry. The two companies continued to produce fuse No. 100 until the middle of 1917, when Piccard Pictet turned over entirely to fuse 106 and for some months supplied the greater part of the total requirements for this fuse.

The greatest difficulty encountered in connection with Swiss contracts was always the supply of material. Nearly all the necessary brass and steel had to be supplied by the Ministry and the output from the factories was repeatedly checked by the inadequate quantities of metal available. Hence the deliveries from the earliest contracts did not reach the full weekly rate until February, 1916, owing to the Ministry's failure to deliver material, and the firm claimed damages which had to be covered by the prices agreed upon in the next contract. In view of the shortage during the autumn of 1916 firms were asked to reduce their output in order to avoid a total stoppage and deliveries were very low in November. An illustration of the difficulties encountered may be drawn from the experience of the firm of H. Cuenod, of Geneva, with whom a contract was signed in March, 1916, for 750,000 No. 83 fuses. The brass for these was ordered from America and was expected in mid-April. By the end of July only a part of the necessary quantity had arrived and the quality of the brass was bad. Thus the first delivery of fuses was made in November, 1916, when the contract should have been finished, while by February, 1917, only 50,000 had been completed. Similarly the lack of metal delayed the production of the No. 106 fuse, the contract for which was signed in September, 1916, but could not be carried out until the following year, manufacture being suspended for want of steel from England as well as brass from America. The most stringent regulations were enforced to secure the proper use of material which was supplied. In addition to an elaborate system of export and distribution means were evolved for the constant inspection of works and the comparison of the output of fuses with the allocations of metal.

By September, 1917, in view of the decline in the exchange the Treasury advocated the closing down of Swiss contracts. The supply department insisted on maintaining a minimum production of 300,000 fuses weekly to avoid diversion of capacity to the enemy, and during the spring of 1918 small contracts were placed pending the final settlement of the question. In April, however, the War Office requirements of fuse No. 106 were reduced and the contracts were terminated in May. The total number of fuses ordered in Switzerland was some 25,500,000 and in addition to these over 116,000,000 fuse parts were purchased. The quality of the output was very satisfactory, the number of rejections being usually the lowest on record.[2]

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[1] (Printed) *Weekly Report*, No. 5, I (28/8/15).
[2] Hist. Rec./H/1145/1.

(e) MANUFACTURE OF TIME AND PERCUSSION FUSES.

The tremendous development of production was intended to provide all types of fuses required, but it may be traced particularly in the case of the most important types issued. During the first months of the war the fuse in most general use was the No. 80, T. and P. fuse, which was assembled in 13-pdr. and 18-pdr. shrapnel and in a certain proportion of H.E. shell. For two years previous to August, 1914, production had been limited to the Ordnance Factories and Messrs. Vickers, and it was necessary on the outbreak of hostilities to secure very much larger supplies. First the other armament firms and then trade companies were brought in, while in order to hasten deliveries, deviations from specification were allowed. Nevertheless, in spite of concessions as regards metal, considerable delays occurred, largely owing to the difficulty experienced in obtaining plant—a problem which remained as a serious check on production throughout 1915.[1] In March, 1915, sums were advanced for the erection of new No. 80 plant, which was to be at the disposal of the War Office during the war and then only dismantled on one year's notice from the contractor.[2] Deliveries were thus approaching demands on the formation of the Ministry, but there was still a very large deficiency in stocks. In the summer of 1915 the output of No. 80 was threatened by the shortage of aluminium, of which the body was then made. Stocks accumulated by the Ministry were of a very inferior quality which delayed the process of machining. In October, 1915,[3] the substitution of brass for aluminium was approved, but the brass fuse met considerable opposition from manufacturers, some of whom contrived to continue the output of aluminium bodies until after July, 1916.[4] In the autumn of 1916 labour difficulties impeded output and the supply of material again became difficult. Instructions were then given to cease manufacture in both aluminium and brass and to change to steel or malleable iron,[5] while experiments were also made in zinc alloy,[6] but it was eventually proved that none of these materials was really suitable for fuse No. 80 and its manufacture was confined to brass and aluminium.[7] The shortage was not really overcome until 1917. In spite of all efforts the deliveries in November, 1916, were very much below the requirements, but in the following year arrangements were made to secure an output providing a safe margin over requirements. In March it was possible to rely entirely on home manufacture to supply fuses for 18-pdr. shell and large stocks were accumulating, but orders in America were continued to maintain a good reserve.[8] Fuse No. 85 was practically identical with No. 80 except in its percussion mechanism and was made only in America.

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[1] 94/F./542, 328 and 2611.
[2] 94/F./63.
[3] *Ordnance Board Annual Report*, 1915.
[4] 94/F./1129.
[5] HIST. REC./H/1320/1. (2).
[6] *Order and Supply List*, No. D. 93.
[7] HIST. REC./H./1320/12.
[8] D.D.G. (A.) 15081.

Production of the long-burning fuses was delayed by serious problems. The bulk of fuse No. 83 was produced in Switzerland by a firm which was making No. 100,[1] while No. 88 was manufactured only by the Ordnance Factory.[2] In February, 1916, to meet a pressing demand for long-range fuses, the Ordnance Factory and Messrs. Armstrong changed over from the manufacture of fuse 80 to that of 87 so rapidly that an output of 18,000 was reached in about ten days.[3] The armament firms, the Ordnance Factory and Swiss contractors continued to produce the greater part of the long-range fuses supplied, but none of the powder-burning fuses had been entirely satisfactory as the time taken in burning was not long enough and could not be absolutely regulated. The great difficulties encountered in the blending of materials to obtain a powder burning within the specification limits also hindered production. Manufacture of the slow-burning composition which had been developed by the Research Department was particularly dangerous and contractors were unwilling to take up its production. In August, 1917, one firm, however, contracted to supply 800 lb. weekly from Government plant, while the Technical Section undertook exhaustive experiments with various powders and effected some improvement, and by March, 1918, most of the manufacturing difficulties were overcome.[4]

In August, 1917, the Cambridge Scientific Instrument Company undertook the work of reconstructing the mechanism of the clockwork fuses which were recovered from exploded German shell and received an immediate order for 20,000. One of the managing directors of the company was attached to the supply department and agreed to remain so until the first 2,000 were satisfactorily passed. The first trials of the British clockwork fuses, carried out in April, 1918, resulted in a very large percentage of blinds, but in the following month some unused German fuses were captured and submitted to the company for comparison. This gave a fresh impetus to the work and by September the experimental stage was practically complete, the fuse being in supply to the extent of a few hundreds weekly. The difficulties of production, however, were very great, as the mechanism was most intricate and quite outside the ordinary lines of munitions manufacture. Since the watch-making industry in England was almost extinct, it was nearly impossible to find firms experienced in work of the necessary kind, and in the case of at least one firm, the manufacture was started up from the beginning on machinery imported from Switzerland.[5] It had been anticipated that 2,000 weekly could be manufactured by Christmas, 1918, but the calling up of a large number of men in March, 1918, and the munitions strike at Coventry, occurring just after the influenza epidemic, thoroughly disorganised production, with the result that by the date of the Armistice the fuse had only been used for trials and was not issued for service.[6]

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[1] *Firms and Factories List.*
[2] *Order and Supply List*, D. 93.
[3] (Printed) *Weekly Report*, No. 30, I, (19/2/16
[4] Vol. X, Part IV, Chap. IX.
[5] HIST. REC./R/1320/9.
[6] *Ibid.*

(f) THE SUPPLY OF PERCUSSION AND GRAZE FUSES

The fuse No. 44, the percussion fuse which was about to come into supply at the outbreak of war, was one of the first to be manufactured by the trade apart from the armament firms. The War Office contracts of November, 1914, with the Sterling Telephone and Electric and the Raleigh Cycle Company provided for 7,500 fuses weekly rising to 25,000 by the end of 1915 and a contract was signed in the same month to obtain 50,000 monthly from America.[1] Early in 1915 two contracts were placed with motor manufacturers for fuse No. 44, and in June, 1916, new plant was erected at Woolwich to meet a particularly urgent demand.[2] No additional firms ever undertook contracts for No. 44 and the Ordnance Factory together with the five firms mentioned above continued to produce all the supplies issued, although two or three contracts were placed in 1916 for the No. 44/80.[3] Early in 1917 a large number of blinds was reported from fuse No. 44. Some variations in the method of filling were introduced without complete success, and slight changes were accordingly made in the design, the earlier marks being converted to Marks III,* IIIa* and IV. These modifications combined with further improvements in filling were so successful that rejections, which during the early months of 1917 had formed a large proportion of deliveries, became very rare.[4]

In 1916 the greatest demands made were for graze fuses of the No. 100 type. This fuse had been in process of evolution towards the end of 1914 when the War Office negotiated for contracts, but the design approved on 29 December, 1914, was revised and modified on various occasions until April, 1915.[5] During the following months the perpetual issue of new drawings and specifications hampered contractors in starting up and the first delivery was not made until 21 Jnne, 1915.[6] Empty fuses were coming in to the Ordnance Factories for filling in July, 1915, and the issue of filled fuses began in the first week of August. In this and the next month the requirements for the new fuse were greatly increased owing to the failure of the No. 44 fuse used in conjunction with the No. 80, and numerous contracts were placed in France and Switzerland and with various munitions committees as already described.[7] The deliveries were thus quadrupled between August and October, but reports as to the quality of the fuse were not satisfactory.[8] As the change in the gaine used with the fuse[9] failed to remedy the defects, the fuse was still considered unsafe in January, 1916, and research work produced three variants which were subsequently known as Nos. 101, 102, and 103. The first of these was approved on

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[1] *Firms and Factories List.*
[2] D.D.G. (A.) 15027.
[3] *Firms and Factories List.*
[4] HIST. REC./R/1320/10; *see* above, p. 35.
[5] *Ordnance Board Annual Report* (1915).
[6] Contracts/F./2920, with 94/F./129.
[7] *See* above, p. 51.
[8] (Printed) *Weekly Report*, August and September, 1915.
[9] *See* below, p. 64.

16 February, 1916.[1] By this time contracts for fuse No. 100 were held by two of the armament firms, fifteen trade firms and eleven co-operative groups or national factories in addition to Swiss, French and American companies, and on 22 March, 1916, a conference of the principal contractors was held to discuss the required change over to No. 101. This was to be accomplished as soon as possible, but to maintain output in the meantime arrangements were made to convert No. 100 fuses to No. 102, which differed from the former only in the omission of the percussion pellet and the insertion of a detonator into the graze pellet. The manufacturers estimated that the change over would take from two to eight weeks, and drawings for the No. 101 were issued in April with the information that no other graze fuse would be accepted after 30 June.[2] This date, however, had to be extended as none of the new type had been issued by 26 June[3] and the conversion of fuses in stock was also proving a matter of difficulty.

On 3 February, 1917, the manufacture of No. 100 type fuses in cast-iron was officially approved,[4] and in June, 1917, the first deliveries were made of No. 103 in cast-iron.[5] Some difficulty was experienced in carrying out the rust-proofing process necessary for steel bodies, and very strong opposition to the introduction of this fuse was roused, especially from Boards of Management dealing with small sub-contractors. By October, 1917, the output reached 76,000 weekly, but the design was only regarded as temporary.[6] While the output of No. 101 was rising considerably during the summer of 1916 a large number of prematures was reported and many trials were held to investigate the cause of these. It was decided that they were usually due to the detonator's firing on shock of discharge, and a safety shutter opened only by centrifugal force was introduced into this fuse.[7]

Negotiations for contracts for the No. 106 fusebegun in June, 1916,[8] had been interrupted by further alterations in design, but in August, 1916, definite approval was given for the issue of No. 106 to replace the 100 type in all 4·5-in. howitzers and 3·7-in. mountain howitzers, while by 3 November the fuse had been allotted to 50 per cent. of the 6-in., 8-in., and 9·2-in. howitzers. The output of the fuse in brass rose steadily throughout the winter of 1916–17. In December, 1916, satisfactory experiments were made with cast-iron fuses, but in view of the urgent need for output it was impracticable to delay production by changing over the brass manufacturers already at work to cast-iron. Arrangements were therefore made to place orders in cast-iron with other firms in excess of the actual demand.[9] The first deliveries of these were made in July, 1917, but by October the output was still

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[1] (Printed) *Weekly Report*, No. 30, VII (19.2.16).
[2] 94/F./883.
[3] C.R./4552.
[4] (Printed) *Weekly Report*, No. 78, IX (3.2.17).
[5] D.D.G. (C.)/C.M.G./261/1.
[6] M.C./899.
[7] D.D.G. (C.)/C.M.G./261/1.
[8] (Printed) *Weekly Report*, Nos. 49 and 51, III (8.7.16 and 22.7.16).
[9] D.D.G. (A.) 18122.

considerably below the estimate, delays being due not to difficulty with the cast-iron part, but with the complicated brass centre piece, while manufacture was also hampered by a lack of screw gauges.[1] Nevertheless, the total output of brass and iron No. 106 fuses had reached 150,000 by April, 1917 and in the same month deliveries began to come in from Swiss firms who subsequently provided the bulk of the supply. From this time deliveries usually exceeded promises and it was anticipated that all requirements for 1918 would be easily covered.[2] In the summer of 1918 the demand for this fuse was reduced, and the opportunity was taken to make considerable reductions in prices paid, both for the brass and the cast-iron type.[3]

(g) PRACTICAL DIFFICULTIES IN THE MANUFACTURE OF FUSES.

In 1914 the need for immediate output took first place and financial questions were of necessity a secondary consideration. The prices quoted for fuses by the armament firms rose at once in August, 1914, and in view of the urgency of the demands, the War Office accepted them, but in some cases secured a promise of future revision.[4] When the first critical stage was passed, it was decided in August, 1915, that on continuation orders a reduction of 6*d.* to 1*s.* per fuse should be made after a contract had been running from four to six months, the amount varying according to the size and suitability of the firm and the size of the order in question.[5] Further reductions were made later and by August, 1916, certain prices were considerably decreased. For instance, the sum paid to Messrs. Vickers per fuse for No. 80 was reduced from 15*s.* 6*d.* to 12*s.* 6*d.*, and for No. 87 from 15*s.* 6*d.* to 12*s.*, making, for a period of six months, a total difference of some £500,000.[6]

The supply of material was always a matter of difficulty. Fuse factories required very large deliveries of brass, as, owing to the complicated nature of a fuse, more than 50 per cent. of the material became scrap. In 1917, for instance, the weekly tonnage of brass delivered to the manufacturers was 3,100 while the weight of finished fuses was only 1,473 tons.[7] In 1915 and 1916 a considerable proportion of brass was imported from America and deliveries were very irregular. Many of the contractors were supplied with metal by the Ministry at a fixed scale of prices, but in 1917 the position became critical. From time to time various proposals had been made by British and American firms to use cast-iron for the outer parts[8] but in view of the heavy strains set up in the gun, and the difficulty of devising a method of rust-proofing iron which would be suitable for a body containing small parts and delicate mechanism, manufacture in iron was not at

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[1] M.C./899.
[2] D.D.G. (C.)/C.M.G./261/1.
[3] (Printed) *Weekly Report*, No. 146, I (15·6·18).
[4] Contracts/F./2288 with 94/F.542.
[5] 94/F./295.
[6] HIST. REC./R/400/22.
[7] *Ibid.*/H/1840/2.
[8] 94/F/392.

first adopted. As the shortage of brass became acute further attempts were made to obtain satisfactory iron fuses, and the production of the No. 103 followed, while later No. 106 was also made in iron. Rust-proofing still remained a difficulty. The usual method was to heat the fuse bodies to a certain temperature and then quench them in oil, but this was liable to leave an excess of oil in the interior which tended to retard the movements of the parts. Production of fuses in brass and iron proceeded concurrently, but the iron fuse always required a centre bush of steel or brass. Considerable difficulty arose also in obtaining suitable steel for the needles. These sometimes broke on the shock of discharge, firing the fuse prematurely in the gun. Before the end of 1917, however, as a result of the development of brass supplies on which much attention had been concentrated, the production of stampings was overtaking requirements, so that the output of fuse bodies in the United Kingdom reached 1,750,000 weekly and the Ministry was in a position to offer brass supplies to the French.[1]

In consideration of the scarcity of metal, attempts were made whenever possible to rectify or utilise fuses rejected on inspection. At first rejected fuses were returnable to the makers and could be re-submitted after rectification, but so large a number of such fuses failed to pass the second inspection that this system was much modified in 1916.[2] Defective fuses were then put to other uses. Many were made into fuse plugs,[3] while large rejected deliveries of fuse No. 80 were converted, chiefly by Messrs. Vickers, into No. 31 for use in practice with 60-pdr. shrapnel shell.[4] In certain cases, as at the Coventry Ordnance Works in February, 1916, salvaged fuse caps and parts were cleaned and repaired for use.[5] While so many orders were placed with overseas firms it was necessary to provide capacity for the rectification of rejected fuses which could not be shipped back to the makers. This became particularly urgent when the alterations were made in the No. 100 type, and for this purpose a London factory was equipped and operated under an agency agreement by Messrs. Cubitt & Co., to convert No. 100 fuses to No. 102 at the rate of 200,000 weekly.[6]

The solution of problems of design and material was not the only preliminary to the full development of fuse production, which presented manufacturing problems of a peculiar nature. Every type of fuse contains very many minute parts and components, all requiring extreme accuracy of manufacture to secure the efficient functioning of the fuse. The intricacies of the mechanism made the supply of gauges a preliminary question of the utmost importance and this difficulty was increased with every change in design necessitating the provision of new gauges. So great was the strain to which the fuse would be subjected

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[1] Hist. Rec./H/1840/2; *see* Vol. VII, Part III, Chap. IV.
[2] 94/F/1273.
[3] 94/F/1244, 1245 and 1485.
[4] 94/F/732, 870.
[5] 94/F/779.
[6] 15/Muns./2554 and 94/F/1259; *see* Vol. VIII, Part II, Chap. IX.

and so disastrous the effect of prematures arising from small discrepancies that the closest inspection was imposed and the tolerances permitted in the different parts were very small. The only industry involving work in any degree comparable is that of watch and clock making, which was practically non-existent in England before the war. It was therefore no easy matter for electricians, engineers, or firms experienced only in the production of such articles as telephones, gramophones, tools, and machinery to take up, and train workers for, the manufacture of fuses. The enormously increased supplies obtained during the last year of the war are sufficient testimony to the success of their attempts, and the organisation of the fuse industry from the many miscellaneous factories entirely inexperienced in the work remains one of the most striking features of munitions supply.

IV. Fuse-filling.

Before August, 1914, contracts or orders for the filling of fuses apart from their manufacture were practically unknown, fuses being made and filled by the Ordnance Factories, Woolwich, or the armament firms, either under orders for filled fuses or, later, as part of complete rounds.[1] In normal times the Royal Laboratory produced a large proportion of the total issue of filled fuses,[2] but had little spare capacity, so that on the outbreak of war it was necessary to rely more largely on the armament firms and additional contracts with them were immediately signed. Thus by the end of August, 1914, orders had been placed which should have brought in more than 10,000 filled fuses weekly from November, a quantity little less than the average weekly delivery from Woolwich at that date. Deliveries under these contracts failed to come in at the rate which was anticipated and the majority of the firms were still greatly in arrears at the end of the year. In October, 1914, the King's Norton Metal Company, a firm of ammunition and metal manufacturers, undertook to make and fill fuses No. 65A at the rate of 4,000–5,000 weekly in November, and in December a contract was also placed with the firm for filled fuses No. 82.[3] Attempts were made to increase the output of the armament firms, but in addition to the delays occurring in the manufacture of the empty fuse, the difficulty of obtaining a trained staff for filling operations remained a limiting factor in production for some time. The shortage of fuses which resulted from this position led on the one hand to the development of the further resources of the trade for the production of empty fuses, a matter which has already been dealt with, and on the other to the expansion of filling capacity. In February, 1915, the first contract for filling only was signed with Messrs. George Kent, a firm of hydraulic and general engineers, who undertook to reach a weekly output of 8,000 No. 44 fuses by April in a factory to be built for the purpose.[4] Similar contracts followed with Messrs. Bickford, Smith & Company, the makers of the

[1] HIST. REC./H/1122.1/1 and *Order and Supply List.*
[2] *See* above, p. 7.
[3] *Order and Supply List.*
[4] HIST. REC./H/1340/1/Chap. XI.

Bickford fuse used for engineering purposes, and the Thames Ammunition Works, which had formerly acted as sub-contractors to Messrs. Armstrong, Whitworth and Company. Early in the year (1915) a large contract for filled fuses was placed in America, and in addition to the contract for filling fuse No. 44, Messrs. George Kent undertook orders for making and filling No. 65A. At the same time the King's Norton Metal Company considerably increased their output, but on the whole orders from the trade apart from the armament firms were only for empty fuses.[1]

In May, 1915, extensions were made to the factories at Woolwich to provide for filling the empty fuses produced by the trade and the filling capacity was very largely increased, the estimated July output being 60,000 fuses.[2]

On the formation of the Ministry, the output was still much below requirements, and as the new filling capacity at Woolwich was completely absorbed, additional works were urgently required to fill the fuses which were beginning to be manufactured in considerable quantities by a variety of firms. The spreading of contracts for filling beyond the armament firms was still limited to the two or three companies mentioned above, but very large orders were placed with the armament firms themselves, and by September, 1915, the actual deliveries from these reached over 100,000 filled fuses weekly,[3] approximately 40,000 more than the corresponding output from the Royal Laboratory.[4] In November, the American deliveries were coming in well and the weekly average of fuses filled by overseas contractors was 62,535, as compared with the total home deliveries of 281,197.[5] In spite of these developments not only was the supply of filled fuses inadequate to the demand but filling was unable to keep pace with the manufacture of empty fuses.[6]

By the beginning of the autumn, 1915, the scheme for the erection of the National Filling Factories[7] had fully developed and in addition to the shell-filling programme, provided a very large capacity for filling percussion fuses. No one factory was erected for this purpose alone, but two, those at Coventry and Perivale, were laid out to fill fuses and minor components, two others at Gloucester and Hayes for these as well as shell-filling, while the Abbey Wood factory which was at first intended only for minor components began to fill fuses as well in April, 1916. In addition to these, the Southwark Factory was designed to handle all kinds of components in any emergency and by June, 1916, was filling 5,000 fuses weekly. Fuse-filling began in Hayes in October, 1915, and the other factories started up at various dates throughout the winter, but the lack of experience and the entire absence of trained experts in the commercial world caused considerable delay.

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1 *Order and Supply List.*
2 *See* above, p. 9.
3 *Order and Supply List.*
4 Hist. Rec./H/1122.1/1.
5 (Printed) *Weekly Report*, No. 21, I.E. (18.12.15).
6 *Ibid.*, Nos. 19 and 20, I.E. (11.12.15 and 18.12.15).
7 See above, p. 18.

For various reasons, chiefly concerned with design, the output of filled No. 100 fuses fell behind that of the empty fuse during the winter of 1915–16. In the case of time and percussion fuses, which were either filled by the Ordnance Factories at Woolwich or delivered filled by contractors, the returns of empty and filled fuses were fairly balanced. The large quantities of graze fuses obtained throughout the winter from British and American firms were allocated to be filled at the five new national factories laid out for filling components. The first of these to start up after the Hayes Factory was that at Perivale, which began work on 1 December, 1915. Filling began at Abbey Wood on 1 January, 1916, and in March, 1916, operations were started at Gloucester, where construction had not begun until October, 1915, and at Coventry, which had been delayed by difficulties encountered during construction. During the summer good progress was made, and by September, 1916, the new factories had practically all reached their full estimated output and were delivering some 500,000 percussion fuses weekly,[1] or rather more than seven times the average Woolwich output at that date.[2]

Although the initial difficulties were by this time nearly all overcome, further troubles arose as to the quality of the filled percussion fuses issued. During the winter of 1916–17 numerous prematures reported from France and from trials at home were found to be due to fuses filled at the Coventry Filling Factory. Further investigations showed the fuses to contain detonators inserted upside down or unduly sensitive, and the issue of fuses from the factory was stopped, while in December, 1916, the use of ammunition containing them was prohibited. The factory was entirely reorganised, and in February, 1917, all fuses and gaines filled before the investigation were emptied and refilled, the factory's number being changed in order that the new fuses issued should not be regarded with suspicion. Measures were also taken to raise the standard of the detonators supplied to the factory.

Throughout 1916 and early in 1917 much difficulty was experienced by the filling factories as a result of the various changes in design in the graze fuses;[3] but after the introduction of the No. 106 fuse the rate of filling became quite equal to that of manufacture, and the supply of empties became the limiting feature in production. At the same time the filling factories complained in May and June, 1917, that the empty fuses supplied to them were frequently defective, so that their work was delayed by the necessity of instituting a further inspection before filling.[4] With the improvement and development of the supplies of empties the filling factories were able to work smoothly, and by the end of the year requirements were being met. No wider development of fuse-filling capacity was made after the organisation of the national factories, and these, together with the armament firms and the two or three others which began filling in the winter of 1914–15, provided the bulk of the capacity required for percussion fuses. By 1917, the Ordnance Factory

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[1] For the details of their work see Vol. VIII, Part II, Chap. V.
[2] HIST. REC./H/1122.1/1.
[3] C.M. 4/1275.
[4] D.D.G. (C.)/C.M.G./261/1.

was filling only a very small proportion and was regarded principally as a stand-by in emergency and as a filling factory for experimental fuses or those which were only required in small quantities. With one exception none of the national factories dealt with time or time and percussion fuses. Coventry, alone, took up this work and that at a comparatively late date.

IV. The Supply of Empty Components.

(a) GAINES, PRIMERS, AND TUBES.

At the outbreak of war the Ordnance Factories formed the main source of supply for all minor components for gun ammunition, the manufacture of the empty parts and the subsequent processes of filling and assembling being all carried on at Woolwich. Shrapnel shell were delivered complete with tubes and cups but after August, 1914, the additional requirements of the Services for components for H.E. shell were met by direct contracts with the established armament firms throughout the country who in their turn drew fresh resources from the general engineering industry by passing on to sub-contractors such work as was beyond their own capacity. These firms were producing the greater part of the components issued in 1914, but by the end of November it was realised that a more general effort would be needed to cope with the rapidly increasing demands for ammunition, and consequently firms which in normal times were engaged in very different forms of work began to take contracts for the manufacture of components in addition to the plugs and clips which had always been obtained from private firms.[1] It was found possible to adapt plant previously used for the manufacture of practically all kinds of engineering accessories and metal smallware, so that by the following year the firms producing components under contract with the War Office included peace-time makers of such articles as textile machinery, gramophones, and sewing machines, chains, hooks and tools in variety, gas fittings, typewriters, and printing machinery, cycles and motors. In November, 1914, the Canadian Government began to undertake orders for cartridge cases, although the quantities promised were small compared with those of later contracts. In March, 1915, a considerable increase was made in the number of contracts placed with British firms, while in the same month American companies began to undertake the production of small components.

In spite of these efforts the position on the formation of the Ministry was serious.[2] A considerable shortage of components obviously existed, and the difficulty was intensified by the absence of adequate reports from contracting firms. Returns of actual deliveries had been made, but there was in operation no established system by which progress or difficulties arising in the course of manufacture could be ascertained, with the result that congestion would occur in one factory simultaneously

[1] *Firms and Factories List.*

[2] HIST. REC./H/1300/1.

with a serious scarcity in another, while shell-works were frequently forced to suspend operations for a time through lack of various components.[1] The co-ordination of the different parts necessary for complete rounds had not been satisfactorily assured.[2] Thus, on the War Office orders due in October, 1915, there was a deficit of some 40,000 gaines, while the adequate provision of primers depended on the recovery of a repairable 33 per cent. from the front, a supply which was liable at any time to be cut off or greatly reduced. In other respects the balance was very fairly maintained as regards orders, but it was difficult to enforce a corresponding delivery. In the case of certain Canadian contracts, for instance, where orders were placed for complete rounds, shell were delivered without certain essential components for which manufacturing arrangements had not been made, and the necessity of completing these shell threw out the balance of home supplies.

The Shell Manufacture Department of the Ministry had therefore to take immediate steps to overcome these difficulties. The institution during the winter of 1915–16 of regular returns[3] and an organised system of progress reports facilitated the work of organisation and incidentally afforded considerable assistance to manufacturers, resulting in an increase in their output. Arrangements were ultimately made to place further contracts and acquire a stock of each component in bond, so as to meet any emergency demand which might arise. In many cases contracts with firms formerly executing War Office orders were renewed, but a large number of new orders were placed with similar firms. Where possible small firms were selected and concentrated on the mass production of particular articles, to avoid the uneconomical use of skilled labour and plant entailed by the constant changing over from one type of work to another.[4] In addition to the development of supplies from individual trade companies, the local co-operative groups, which had been initiated shortly before the inception of the Ministry, undertook a considerable proportion of the work on minor components. In this way use was made of small local firms which did not possess the plant necessary to the production of complete shell or of firms which were already engaged on Government contracts for munitions or machinery but had some spare capacity. Such firms frequently undertook the manufacture of component parts which were assembled for finishing and inspection in a central factory.[5] Production under this system increased during the summer, and by November the deliveries of components were very considerable. The large demands for component parts led also to the formation from this time onwards of new companies which afforded fresh sources of supply.[6] Most of these were comparatively small ventures, but one firm at Birmingham, which was established for component production and began work about November, 1915, employed over 3,000 workers and undertook large orders for gaines and

[1] HIST. REC./H/1300/15.
[2] *Ibid.*/H/1320/1.
[3] *Ibid.*/H/1300/1.
[4] *Ibid.*/H/1300/15 and *Firms and Factories List.*
[5] Vol. I, Part III, Chap. I and IV.
[6] *Directory of Engineering Firms.*

adapters as well as a contract for 1,300,000 fuses. In September, 1915,[1] the Ministry completed negotiations which had been in progress with the French Government and arranged for the placing of contracts with French firms, principally the Compagnie Générale d'Electricité and the Eclairage Electrique, for the production of 2,000,000 gaines. About the same time, orders were placed in Switzerland for weekly deliveries of 200,000 primers, 200,000 T. tubes, and 250,000 fuses with gaines.

The arrangements thus made to meet the first Ministry programme produced a considerable rise in output during the autumn of 1915, and it was hoped that this improvement would be steadily maintained. From November, 1915, however, a series of checks on the output of shell was imposed by difficulties arising from the manufacture of particular components.[2] From the middle of November, 1915, to the end of February, 1916, the trouble was due to the change in design of the gaine used for H.E. shell.[3] By 13 November the deliveries of H.E. shell had reached nearly 130,000 weekly. A small proportion of these were fitted with a No. 17 or 44 fuse, but all other fuses had to be assembled with a gaine. During the late autumn numerous prematures were reported, and investigations showed that the combination of the No. 80/44 fuse with a No. 1 gaine (the existing type) was particularly dangerous. At first it was proposed to abandon the No. 80/44 fuse, but it was proved that the trouble lay with the gaine itself, which was too heavy and frequently broke away. Various temporary remedies were tried, but the Ordnance Board concluded that only a new type of gaine, shorter and lighter, would satisfactorily solve the problem. To secure good detonation of amatol, this gaine had a detonator of 10 grains of fulminate of mercury placed immediately above the charge of tetryl in its magazine. The new design thus necessitated the revision of all contracts for gaines, and the provision of 10-grain detonators. The design was approved on 24 November, and although supplies could not be obtained within six weeks, on 2 December the War Office refused to sanction the further acceptance of long gaines. Accordingly only shell which could be assembled with a No. 17 or 44 fuse could be issued, and the output fell rapidly to some 22,000 weekly, no 18-pdr. H.E. shell being completed at all. The change in manufacture was effected as rapidly as possible, and contracts were placed with the armament firms for the 10-grain detonators, but no deliveries were possible before January, 1916. In that month[4] small deliveries of the No. 2 gaine began to come in from home firms, and the Royal Laboratory, Woolwich, produced 110,000 detonators. A detonator produced by Nobel's Explosives Company was approved as an alternative to the R.L. design, and the first output was hurried down by special messenger from Nobel's works at Glasgow for proof at Woolwich, thus releasing 30,000 for the week ending 29 January. By 22 January the weekly output of H.E. shell was raised to 120,000. Deliveries of No. 1 gaines continued to come in from America for some weeks after

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[1] *Firms and Factories List.*
[2] (Printed) *Weekly Reports*, from November, 1915–March, 1916.
[3] Hist. Rec./H/1300/1 (enclosure G.)
[4] C.R./3008.

their condemnation and arrangements were made with firms, chiefly the various railway companies, to carry out the work of shortening them. Throughout February, 1916, the British contractors were in full swing on the new design, American firms had changed over, and the weekly output reached 400,000, while in March the 10-grain detonators were also coming in well.[1] In spite of the railway companies' work a large store of No. 1 gaines was still in stock late in 1917, and after much consideration was condemned as scrap, as, owing to the high cost of breaking down and remaking, nothing was to be gained by their conversion to the later type.[2]

In June, 1916, a further set-back in shell production occurred owing to the difficulty which arose in producing exploder containers. These were not used during the first eighteen months of the war, but were introduced at the beginning of 1916, as part of the prolonged efforts then made to improve the system of detonation. Containers were designed to secure a close contact between the gaine and the exploder, and also to seal the shell after filling, but although manufacturers were consulted as to the design, production was only developed with difficulty,[3] and partly in consequence of the issue of H.E. shell without containers the quality of this kind of ammunition continued for some time to be very unsatisfactory. Trouble was experienced in producing the tubular part of the container on account of the scoring and splitting of the steel during the flanging operation.[4] By the end of June four firms, whose contracts provided jointly for 140,000 containers, succeeded in working out a successful treatment of the steel, and arrangements were made to transfer additional plant to them.[5] But the increased output anticipated did not materialise, as the steel tubing itself was not delivered, and in July the output of containers was only 10,800 a week. In August production was much improved but fresh complications followed owing to the scarcity of gauges, which resulted in deliveries being either held up or inadequately inspected at the works and consequently rejected at proof. From July to September, 1916, rejections averaged 41 per cent. of the total deliveries, and it was not until late in the autumn that the supply improved as gauges became available.[6]

Before the situation was cleared as regards exploder containers, trouble arose in connection with the manufacture of tubes and primers. As early as March, 1916, it had been suggested that the Ordnance Factories should lend experts to the various firms undertaking production of friction tubes, as the Ordnance Factories and Coventry Ordnance Works were the only experienced and reliable sources of supply and the issue of the heavier natures of shell during the summer was likely to be delayed unless the provision of tubes was more adequately developed. From August to October, 1916, a serious scarcity was chiefly due to the shortage of material. At the end of August heavy rejections were made, since one of the largest producers had used scrap metal for

[1] (Printed) *Weekly Report*, No. 31, I (26.2.16), and *Firms and Factories List*.
[2] D.M.R.S./541.
[3] HIST.REC./H/1300/1.
[4] (Printed) *Weekly Report*, No. 45, III (10.6.16).
[5] *Ibid.*, No. 47, III (24.6.16).
[6] *Ibid.*, Nos. 51, III, 54, III (July–September), 1916.

manufacture.[1] In consequence the issue of 60-pdr. and 4·7-in. shell was partially suspended for lack of V.S.P. tubes and fuses at the beginning of September, with the result that considerable congestion occurred at the Ordnance Factories, and a loan of 50,000 tubes was arranged from the Admiralty. Contracts were also made with trade firms to rectify tubes rejected at the filling factories, and during September, as fresh sources of metal supplies were opened up, the position began to improve.[2]

The supply of primers had been a matter of very great difficulty in August and September, 1915, although the output of shell had continued to increase until trouble arose with the gaine in November.[3] In the week ending 21 August deliveries of primers were 400,000 less than those of shell requiring them as a result of the delivery of incomplete shell from Canada. At the end of September several new manufacturers were in a position to begin deliveries and earlier contractors were arranging to increase their output, so that the position was much improved during the winter. In August, 1916, however, the output of primers fell with that of tubes from similar causes, but rose again by the end of the year to the rate required. The supply was largely augmented by returns of salvaged ammunition from the front, although the percentage of repairable primers was not so high as that of cartridge cases. For the 1917 programme the requirements were approximately 1,500,000 weekly. Home manufacture could produce 950,000 of these, Canada another 300,000, and no difficulty was anticipated in recovering the remainder from fired ammunition.[4]

During the summer of 1916, repeated complaints were received from various quarters as to the poor quality of the minor components supplied, and attention was focussed on the supply of gauges[5] and the system of inspection. For the twelve months following July, 1915, only a small amount of inspection to guide and help manufacture had been given by the supply department, but in 1916 preliminary measures were taken to organise a more general inspection by the supply officers. From September, 1916, onwards, the work of inspecting components was undertaken by the inspection authorities, certain small stores being inspected by the Director of Inspection, Munitions Areas, and the Director of Inspection, Gun Ammunition (Supervisory), and inspection bonds were established at Dudley and Birmingham, while some components were inspected at the place of manufacture by gauges passed by the National Physical Laboratory.[6]

From 1917 onwards the only difficulties which materially affected the supply of these or other shell components were in connection with changes in design and the shortage of materials required. Thus, during the early summer of 1917, the introduction of the No. 2, Mark II gaine, in place of No. 2, Mark I, affected a large number of contracts. In

[1] (Printed) *Weekly Report*, No. 57, III (2.9.16).
[2] *Ibid.*, No. 58, III (9.9.16).
[3] *See* above, p. 64.
[4] Minutes of the Advisory Committee, 27.10.16.
[5] (Printed) *Weekly Report*, June–September, 1916.
[6] C.R./D.G.S.G./2232.

view of representations made by various contractors in March, the earlier Mark was accepted up to 30 June to avoid the threatened dislocation of output, and in August it was still necessary to fill Mark I, pending an adequate supply of Mark II.[1] In 1918 the manufacturing capacity of the country for all kinds of components was so far developed that in some cases supplies were more than equal to the demands, and spare capacity was released for aero-engine work.[2]

(b) CARTRIDGE CASE MANUFACTURE AND REPAIR.

The supply of cartridge cases and bags in numbers equal to those of corresponding natures of shell was a matter which involved considerable difficulties from time to time, and was one of the first problems with which the Ministry was faced.[3] As regards the brass cartridge cases for fixed ammunition, a shortage which existed in the late summer of 1915 was overcome after a short time, and in November the design for the 4·7-in. cartridge case was radically altered, a shorter case being approved for all except a few coast defence guns.[4] The new case was to be manufactured in the ratio of one case to three shells, to allow for salvage and reforming, and the long cases then awaiting repair were to be converted to the new design.[5] In 1915 the plans for National Shell Factories included a scheme for cartridge case production at Liverpool. In February, 1916, however, the outlook was still very unsatisfactory. The armament firms were already producing to their fullest capacity, the Liverpool factory had not yet started up, and an additional 1,000,000 18-pdr. and 2,000,000 4·5-in. cases had to be ordered from Canada to meet the increasing requirements.[6] Orders were also placed in France. During 1916 production began at the Birtley Cartridge Case Factory, which was originally projected as a part of the Birtley National Projectile Factory, and subsequently rented from the Ministry by Messrs. Armstrong, Whitworth, who worked it under a contract agreement.[7] The Liverpool National Shell Factory also provided 20,000 cases weekly, and supplies increased considerably throughout the year, with the result that by December a large stock was accumulated. Further orders were nevertheless placed in Canada, in order to retain manufacturing capacity which would be required should any emergency arise.[8] During the summer of 1916 a change was made from brass cartridge cases to steel for 4·7-in. shell, but trade deliveries of the steel cases came in so slowly that some contracts for brass cases had to be continued. It was reckoned that one steel case would last 15 rounds, and the manufacturing position was rendered easier when once manufacture in steel had been built up.

Repairable salvaged cases returned from the front always provided a large proportion of the supplies, and, in 1915, 75 per cent. of fired cases were returned, but in view of the uncertainty of these deliveries provision was made for manufacture on the assumption that not more than

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1 D.G.M.D./F./77.
2 HIST. REC./R/1320/8.
3 HIST. REC./R/1340/17.
4 D.D.G. (A.) 9599.
5 C.R. 043.
6 A.C. 71.
7 94/National/103.
8 Minutes of the Advisory Committee.

50 per cent., and usually 30 per cent., would be returned.[1] Repairing shops were erected at Newport and Dagenham during the winter of 1915–16 to supplement the Woolwich capacity, while in the following summer the work was largely carried out by the railway companies. Early in 1917 fresh repairing capacity was required, as large stocks were waiting both in England and France, and the rate at which used cases were being delivered was far more rapid than that at which the repairs could be done. Arrangements were therefore made to set up additional plant at Dagenham, Newport, and elsewhere to re-form 600,000 cases a week. The numbers returned were upon occasion so great that it was considered best to store them in the Ministry depôts before repair, rather than to re-form them as they were sorted and dispatched from the War Office Salvage Station at Richborough.[2] In August, 1917, a fresh source of supply was afforded by the starting up of the Waterford National Shell Factory, which had been planned for the manufacture of 20,000 new cases weekly about a year before. About October, 1917, a fresh scheme was set on foot for establishing a new cartridge case factory at Long Eaton. The plan was specially intended with a view to providing employment for the numerous workers who were usually dependent upon the lace trade, an industry peculiarly fluctuating in its character. The Ministry was to bear the initial cost of establishing the factory, which was to be rented by Messrs. Fenton Bros., and operated by them at fixed contract prices, the Ministry receiving half the profits,[3] but the project was abandoned in the following spring, when, owing to the reduction in the ammunition programme, the demands for cases were met without difficulty from existing capacity.[4]

V. Arrangements for Filling Minor Components.

Before the formation of the Ministry the work of filling minor components was undertaken mainly by the Ordnance Factories, Woolwich, and by the recognised armament firms. Contracts were at first placed with these firms for filled components, but in the spring of 1915, when it was found possible to develop the manufacture of empty parts by ordinary engineering companies, contracts for filling these were given to the Coventry Ordnance Works and to Messrs. George Kent, Ltd., to supplement the filling capacities at Woolwich. In 1914 Messrs. Bickford Smith & Company and George Kent, Ltd., erected new factories for filling gaines as well as fuses, while Messrs. Armstrong Whitworth and Messrs. Vickers were producing complete rounds and also filling additional gaines. Empty primers were not supplied by the trade under War Office orders, but were made and filled either at the Ordnance Factories or by one of the armament firms. Filled primers and tubes were supplied from Canada, but the filling of empty tubes manufactured in Great Britain was only carried out at Woolwich.[5]

[1] (Printed) *Weekly Report*, No. 19, I (4.12.15).
[2] M.C. 113.
[3] M.C. 259; (Printed) *Weekly Report*, No. 115, XV. (27/10/17); No. 121, I. (8/12/17).
[4] Minutes of the Advisory Committee (27/10/16).
[5] Hist. Rec./H/1340/1 and *Firms and Factories List*.

In June, 1915, the Ministry was informed that the filling capacity for the War Office programme was amply provided for by the War Office, and that development such as was urgently required in the manufacture of empty components was not required. It was difficult to gauge the position exactly as no detailed information was available as to the capacities at Woolwich. When the Ministry took over control of the Ordnance Factories on 23 August, 1915, it was found that the outlook was far from satisfactory. The capacity of the different empty component-making firms had been under-estimated and that of the filling shops at Woolwich exaggerated, and although new factories had been designed for the completion and assembly of components ordered by the War Office, there was little prospect of their being ready in time to cope with the anticipated output. Steps were immediately taken by the Ministry to "speed up" the construction of the filling factories and to plan new ones. Stores were erected and an organised method for the allocation of components among the factories was set on foot; additional plant and buildings were rapidly set up to increase the capacity of large firms such as the King's Norton Metal Company and Coventry Ordnance Works, while in four weeks' time emergency filling factories at Hayes and Southwark were starting operations on the filling of gaines, primers, T. tubes, fuses, and detonators to cope with the deliveries of incomplete rounds from abroad. The establishment of the national factories for filling components has already been described.[1] Additional contracts were also placed with trade firms, and after some time arrangements were made to introduce a more accurate system of record that should show the numbers of components in stock, on transit, or at the various filling factories.[2] In December, 1915, when the urgent demand arose for 10-grain detonators[3] these were shipped over to Rouen for filling and transported back to Perivale before being issued in complete shell.[4] On the whole, however, the new detonator-filling capacity was not seriously disorganised by the introduction of the 10-grain detonator, as allowance had been made for a considerable increase in the amount of explosive when the presses were ordered.

Difficulties arose at times in synchronising the filling of shell and components at different factories. In September, 1916, a scheme was drawn up to connect the output of certain shell and cartridge filling factories, usually in the same district. Thus shell from Morecambe Filling Factory were provided with cartridges from Aintree, those from Pembrey were served by Gloucester, etc. This improved the balance to some extent, but in January, 1917, cartridge filling fell for a time much below that of shells owing either to the change over from one propellant to another or to lack of the particular propellant required.[5]

A great part of the work of the Technical Section of the Gun Ammunition Filling Department was concerned with improving the

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[1] *See* above, p. 18.
[2] HIST. REC./H/1300/1; C.R. 4435.
[3] *See* above, p. 64.
[4] (Printed) *Weekly Report*, No. 21, I (18/12/15).
[5] D.D.G. (C.)C.M.G. 213/1.

quality of filled components produced outside the Royal Laboratory, Woolwich.[1]

VI. Textiles and Miscellaneous Materials.

In addition to the larger components the Ministry was responsible for providing adequate supplies of various materials used in the assembly of complete shell. The textiles required for cartridge bags and for other purposes included different makes of silk, serge, shalloon (a kind of serge), felt, cambric, and batiste.

Some idea of the amount and variety of the materials consumed in the filling and completing of ammunition may be obtained from the following table of weekly requirements as estimated in January, 1916 :—

Weekly Requirements of Textiles and other Materials for the Ordnance Factory and Filling Factories, January, 1916.[2]

	Yards.		Cwts.		Gallons.
Batiste	12,000	Boards, Leather	150	Methylated Spirit	157
Shalloon Braid	5,000	„ Glazed	651	Turpentine	4
Silk Braid	540	„ Mill	300		
Cotton Cambric	30,000	„ Straw	23		
Silk Cloth	21,586	Felt Sheet	42		
Muslin	22	Glue	4·5		
Shalloon	19,500	Gum Shellac	11		
Japanese Silk	1,800		Lbs.		
Tape, Cotton and Linen	633	Sewing Silk and Twist	229		
Spun Silk Webbing	150	Thread	388		
			Cwts.		
		Starch	5·5		
			Reams.		
		Paper	957		

Until stocks of these materials could be built up, the output of each filling factory rested upon a hand-to-mouth provision of every one of these smaller components. Thus the absence of a small piece of muslin, the size of a sixpence, delayed the whole gaine output of one factory in the spring of 1916 and was quoted by Mr. Geddes in illustration of "the hair by which his sword hung."[3]

In August, 1915, when the Ministry wished to develop the manufacture of bags for B.L. cartridges by the trade, difficulties arose in obtaining the necessary materials as supply had previously been completely undertaken by the Ordnance Factories. It was found essential for the Ministry to become responsible for providing all textiles required by trade filling firms. As the War Office had commandeered all raw materials for woollen goods, it was eventually decided that the arrangements for purchase must be centralised, and from January, 1917, the War Office Contracts Department became responsible for supplies to the Ministry.[4] In February, 1916, when it was found that the inspection of materials at Woolwich could not keep pace with production, a store and inspection centre was opened at Leeds, and at the same time manufacture of textile components was undertaken at and near Leeds as well as

[1] *See* above, p. 35.
[2] C.R. 4436.
[3] Mr. Geddes to Mr. Lloyd George, 15/3/16 ; (C.R. 4437).
[4] Hist. Rec./R/1340/17.

at the Ordnance Factory.[1] This avoided the delays formerly occurring between manufacture and issue to the factories, while from March to May, 1916, the rate of production rose from 80,000 to 300,000 bags weekly and a stock of 1,500,000 was accumulated.[2] By May, 1916, contracts for practically the whole requirements of silk braid for the year were placed with one firm and the requirements of shalloon were also covered, but the supply of silk cloth and sewing silk presented great difficulty. The material for these was imported from Japan; the price rose steadily, and the Ministry could not secure supplies in advance, being forced to buy in small quantities as and when occasion offered. By December, 1916, the supplies available amounted to little more than a quarter of the requirements, and the Technical Section investigated the question of substitutes. In January, 1917, 400,000 filled shell were awaiting cartridges for which bags were not available, and the whole position as regards textiles gave rise to much anxiety. Under an order issued by the Ministry under the Defence of the Realm Acts, 8 November, 1916,[3] a return was made of all silk noils and yarn in stock in the country, and by a further order of 23 July, 1917, the distribution of Japanese silk was controlled, while Messrs. Thomas Taylor & Co., of Manchester, were appointed Government agents for the importation of noils and yarn from the Far East. The supply of silk braids practically ceased at the end of 1916 and the use of shalloon braids was sanctioned as a substitute for tying cartridges. Cream serge was next largely substituted for silk cloth in the manufacture of bags, although silk was still essential for certain guns. The use of serge prevailed more and more extensively throughout the year as the difficulties of importing silk increased, but it was 30 to 45 per cent. more expensive as well as less suitable for the purpose. In October, 1917, a further substitute was introduced which consisted of a mixture of American cotton and worsted with a weight and breaking strain equal to that of serge, and which had the advantage of being less expensive to produce.

At the same time the Board of Trade restrictions on the import of paper, strawboard, millboard, and similar articles, and the reduction of available supplies in Holland, created a shortage of these materials and demonstrated the necessity of developing home manufacture. This production was largely dependent on the return of waste from the filling factories, and in 1918, when various small paper components were discarded, sufficient to meet the minimum required by the Ministry was obtainable.[4]

Other requirements included plugs, clips and discs of various kinds which were always obtained without much difficulty from trade firms,[5] glue and shellac putty, required for securing small parts, particularly in fuses and detonators. The highly sensitive explosive, fulminate of mercury, which was essential as the initiating agent for firing practically every fuse, shell, or cartridge, was obtained with comparative ease from a few well-established manufacturers.

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[1] C.R. 4436.
[2] D.D.G. (C)/C.M.G./315.
[3] *War Materials Supplies Manual* (28.2.18), p. 313.
[4] D.D.G. (C)/C.M.G./315.
[5] C.R./Filling/17.

CHAPTER VI.

REVIEW OF OUTPUT.

I. Completed Ammunition.

In a little over four years, more than 196,000,000 rounds of gun ammunition were filled and completed in the factories at home, and another 21,000,000 were filled in Canada and the United States for the British forces. These figures, large as they are, scarcely indicate the amount of energy and labour, both administrative and physical, which were necessary to maintain this one side of munition production, occupying a larger *personnel* than any other. The detailed figures given in the accompanying tables may well repay a little study.

(*a*) Sources of Output.

As will be seen, it was to the Royal Laboratory at Woolwich Arsenal that the War Office looked for filling and completing all natures of shell in 1914.[1] Even the small trade capacity then available was not used at this time, or it was absorbed in naval work. The Royal Ordnance Factory thus bore the whole brunt of filling and completing all gun ammunition supplied to the Army from August, 1914, until the second quarter of 1915, when small quantities of complete field gun ammunition began to arrive from abroad. About that time, also, trade filling factories began to make very small deliveries of the lighter natures; but it was not until the third quarter of 1915 that this output began in good earnest and that a contracting firm also started filling heavier H.E. shell of its own manufacture. Still later in 1915, the new National Filling Factories began to deliver foreign field gun ammunition, which had been received in this country in a semi-complete condition.

Until the spring of 1916 the Royal Laboratory remained the chief centre of filling operations. The number of complete rounds issued thence rose steadily from the 528,000 delivered in the five months ending with December, 1914, to the 4,295,000 rounds issued during the third quarter of 1917. Throughout the war, nearly all the filling and completion of miscellaneous classes of ammunition, such as star and incendiary shell, mountain gun and anti-aircraft ammunition, was undertaken by the Royal Laboratory. It was to secure bulk production

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[1] *See* above, Chap. II.

of the types of ammunition required in vast quantities that the Ministry of Munitions established its nine shell-filling and assembling factories during 1915-1916.

Those of the new national factories which were planned for the comparatively simple operations of filling and assembling Q.F. ammunition came into action early in the year 1916, and the table shows how they outstripped the Ordnance Factory in this work by the second quarter of that year. The filling of the heavier natures of H.E. shell was a much more difficult operation, and the creation of new capacity for this purpose was seriously delayed. At first the work was largely experimental, since the use of heavy H.E. ammunition in the field was comparatively new, while the very size of the gun ammunition programme made it necessary to adopt new kinds of explosive for bursting charges. It was not possible, therefore, to depend solely upon the experience of the Ordnance Factory. It was not until January, 1916, that the exact methods of filling to be used were definitely settled, and it was only by superhuman efforts that the new factories produced their thousand rounds of very heavy ammunition by March, 1916. Six months later, however, they had nearly tripled the combined output of these natures from the Ordnance Factory and the trade together, and were thus supplying a large proportion of the very heavy H.E. shell for the battle period.

The combined efforts of the Royal Laboratory, the national filling factories, and the trade brought the filling and completing of ammunition to its climax during the first quarter of 1917, during which they together delivered 21,028,000 rounds. Only in one subsequent quarter was this figure exceeded. This was during the autumn campaign of 1918, when the output reached 21,143,000 rounds. By that date the supplementary deliveries of complete rounds from overseas had decreased. From the first quarter of 1917 onwards, stringency in the shipping and economic position is shown in a gradual decrease in the filling figures. The capacity which had been created could not now be utilised to the full, for lack of metal, explosive materials, and other essential components of the finished shell. The general policy was to reduce the more expensive methods of shell-filling, such as the work done by contractors at home or abroad, and to limit the filling undertaken within the air-raid areas, *e.g.*, at the Royal Laboratory.

(*b*) Seasonal Variations.

The figures do not, however, show an absolutely steady decrease, since the work was seasonal. As the output of filled ammunition from all sources developed, safe storage became a problem of increasing gravity. Both in France and at home, magazines and dumps were exposed to growing dangers from aircraft attack. The practice of slowing down output during the winter months was accordingly adopted, and during the summer filling went on at extra pressure in order that as much as possible of the completed ammunition might be issued for immediate use.

SHELL-FILLING (OR COMPLETING) FROM AUGUST, 1914, TO FACTORY (WOOLWICH), NATIONAL FILLING FACTORIES AND

(Figures in Thousands.)

		1914.	1915.				1916.	
		1 Aug. to 31 Dec.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st. Qtr.	2nd Qtr.
LIGHT (Category I)—								
A.—Field Gun Ammunition—								
13-pdr. H.E.	O.F.	—	—	13·4	40·8	6·9	24·3	43·1
S.	O.F.	40·6	31·1	34·2	167·3	42·0	38·3	109·6
15-pdr. H.E.	O.F.	·2	·8	1·0	1·8	7·9	·1	7·0
S.	O.F.	8·1	12·3	54·6	50·8	34·0	—	7·1
18-pdr. H.E.	O.F.	9·1	29·6	70·7	247·9	607·5	541·3	727·5
(completing Fgn.)	O.F.	—	—	—	—	24·6	215·3	396·3
	N.F.F.	—	—	—	—	—	—	359·9
(completing Fgn.)	N.F.F.	—	—	—	—	10·6	7·2	726·3
	Trade	—	—	—	—	22·9	1·6	228·0
(completing Fgn.)	Trade	—	—	—	—	—	—	20·5
S.	O.F.	341·7	378·5	597·2	424·4	672·5	535·3	377·4
(completing Fgn.)	O.F.	—	—	—	—	—	182·1	281·8
	N.F.F.	—	—	—	—	—	8·0	215·0
(completing Fgn.)	N.F.F.	—	—	—	—	63·0	176·7	1,027·4
	Trade	—	—	—	160·0*	519·4	869·1	1,082·1
Chemical	N.F.F.	—	—	—	—	—	—	—
Smoke	O.F.	—	—	—	—	—	—	—
Incendiary Q.F. ..	O.F.	—	—	—	—	—	—	—
	N.F.F.	—	—	—	—	—	—	—
Total ..	O.F.	399·7	452·3	771·1	933·0	1,395·4	1,536·7	1,949·8
	N.F.F.	—	—	—	—	73·6	191·9	2,328·6
	Trade	—	—	—	160·0*	542·3	870·7	1,330·6
Total Home ..		399·7	452·3	771·1	1,093·0	2,011·3	2,599·3	5,609·0
Abroad[1] ..		—	—	225·0	561·1	701·2	629·9	1,119·9
B.—Mountain Gun Amn.[2] ..	O.F.	13·4	9·3	2·5	26·0	66·6	62·7	86·5
C.—Anti-Aircraft Gun Amn.	O.F.[3]	2·6	—	1·4	·3	2·2	14·1	165·7
	N.F.F.[4]	—	—	—	—	—	—	—
	Trade[5]	—	—	—	—	—	—	—
Total ..	..	2·6	—	1·4	·3	2·2	14·1	165·7
D.—Tank Gun Amn.	O.F.	—	—	—	—	—	—	—
	N.F.F.	—	—	—	—	—	—	—
	Trade	—	—	—	—	—	—	—
Total ..	..	—	—	—	—	—	—	—
Total (Light) ..	**O.F.**	**415·7**	**461·6**	**775·0**	**959·3**	**1,464·2**	**1,613·5**	**2,202·0**
	N.F.F.	—	—	—	—	**73·6**	**191·9**	**2,328·6**
	Trade	—	—	—	**160·0**	**542·3**	**870·7**	**1,330·6**
	Abroad	—	—	**225·0**	**561·1**	**701·2**	**629·9**	**1,119·9**
MEDIUM (Category II)—								
A.—Gun Amn.—								
60-pdr. H.E.	O.F.	10·9	15·5	21·9	46·5	43·4	76·9	59·0
	N.F.F.	—	—	—	—	—	3·2	106·2
	Trade	—	—	—	1·5	6·2	10·7	37·0
S.	O.F.	19·8	26·5	24·7	47·2	27·3	44·0	61·8
	N.F.F.	—	—	—	—	—	—	60·6
Chemical	O.F.	—	—	—	—	—	—	—
	N.F.F.	—	—	—	—	—	—	—
4·7-in. H.E.	O.F.	1·7	15·8	7·2	21·4	17·3	48·5	42·2
	N.F.F.	—	—	—	—	—	—	12·5
	Trade	—	—	—	—	—	13·6	8·4
S.	O.F.	10·5	—	18·9	11·2	·4	5·8	16·0
Chemical	O.F.	—	—	—	—	—	—	—
Total ..	O.F.	42·9	57·8	72·7	126·3	88·4	175·2	179·0
	N.F.F.	—	—	—	—	—	3·2	179·3
	Trade	—	—	—	1·5	6·2	24·3	45·4
Total ..	..	42·9	57·8	72·7	127·8	94·6	202·7	403·7

* Including small quantities produced since April, 1915.
[1] Imports of complete rounds from U.S.A. and Canada.
[2] Viz., 10-pdr. (H.E. and S.), 2·75-in. (H.E, S., and Star), 2·95 in. (H.E., S. and double), and 3·7-in. How. (H.E.).

DECEMBER, 1918, DISTINGUISHING THE WORK OF THE ORDNANCE TRADE FIRMS AND THE IMPORTATION OF COMPLETE ROUNDS.

(Figures in Thousands.)

1916.		1917.				1918.				Total.
3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	
128·7	80·5	65·4	76·6	68·8	46·8	21·3	93·0	71·4	26·9	**807·9**
154·9	55·3	19·0	44·4	59·3	20·2	21·0	154·4	77·8	62·2	**1,131·6**
9·5	11·9	—	—	12·8	17·9	68·3	5·9	8·0	·5	**153·6**
—	—	5·1	20·0	12·0	26·1	75·1	—	—	—	**305·2**
459·7	439·8	1,141·6	1,197·1	687·7	515·3	471·9	12·2	4·1	—	**7,163·0**
357·8	491·4	256·3	5·7	—	—	—	—	—	—	**1,747·4**
975·4	1,446·2	3,417·2	4,212·1	2,528·3	1,835·6	1,677·0	3,644·2	4,362·6	2,202·2	**26,660·7**
1,414·3	1,901·5	1,090·6	150·7	3·1	·4	—	—	—	—	**5,304·7**
528·3	534·6	737·5	888·2	962·5	979·2	800·7	461·2	378·8	303·2	**6,826·7**
75·1	24·6	—	—	—	—	—	—	—	—	**120·2**
703·2	598·7	803·9	781·8	657·4	343·0	553·6	511·8	775·2	291·4	**9,347·0**
4.7	·5	—	—	—	—	—	—	—	—	**469·1**
1,273·9	1,690·7	2,391·2	1,999·9	1,297·1	1,274·6	1,609·2	3,491·5	3,170·9	1,255·8	**19,677·8**
1,754·2	2,239·3	1,321·7	1,183·7	119·4	73·1	55·6	—	—	—	**8,014·1**
1,272·8	1,187·4	1,161·4	1,037·8	1,043·1	955·1	742·2	1,233·2	1,429·0	928·1	**13,620·7**
—	—	—	—	—	—	—	—	94·7	156·9	**251·6**
—	—	42·2	212·7	220·0	151·4	216·3	285·7	137·5	99·4	**1,365·2**
—	—	—	—	—	—	—	—	5·1	7·3	**12·4**
—	—	—	—	—	—	—	—	9·7	29·3	**39·0**
1,818·5	1,678·1	2,333·5	2,338·3	1,718·0	1,120·7	1,427·5	1,063·0	1,079·1	487·7	**22,502·4**
5,417·8	7,277·7	8,220·7	7,546·4	3,947·9	3,183·7	3,341·8	7,135·7	7,637·9	3,644·2	**59,947·9**
1,876·2	1,746·6	1,898·9	1,926·0	2,005·6	1,934·3	1,542·9	1,694·4	1,807·8	1,231·3	**20,567·6**
9,112·5	10,702·4	12,453·1	11,810·7	7,671·5	6,238·7	6,312·2	9,893·1	10,524·8	5,363·2	**103,017·9**
1,442·3	2,544·0	1,565·5	3,110·9	4,788·8	1,962·8	119·7	323·9	913·7	1,017·9	**21,026·6**
111·9	109·3	102·2	44·5	18·4	5·3	16·0	28·3	29·8	23·1	**755·8**
463·5	551·2	363·5	365·0	562·2	1,082·3	554·9	497·1	360·4	217·1	**5,203·5**
—	—	—	—	—	24·5	96·1	274·3	117·1	48·5	**560·5**
4·9	5·0	—	—	—	—	—	—	—	—	**9·9**
468·4	556·2	363·5	365·0	562·2	1,106·8	651·0	771·4	477·5	265·6	**5,773·9**
2·0	—	2·0	·1	1·8	12·7	9·9	31·6	62·7	32·0	**154·8**
—	—	—	—	—	—	—	104·0	115·1	6·5	**225·6**
92·2	63·0	68·8	117·5	128·1	59·7	2·0	212·3	158·6	77·0	**979·2**
94·2	63·0	70·8	117·6	129·9	72·4	11·9	347·9	336·4	115·5	**1,859·6**
2,395·9	**2,338·6**	**2,801·2**	**2,747·9**	**2,300·4**	**2,221·0**	**2,008·3**	**1,620·0**	**1,532·0**	**759·9**	**28,616·5**
5,417·8	**7,277·7**	**8,220·7**	**7,546·4**	**3,947·9**	**3,208·2**	**3,437·9**	**7,514·0**	**7,870·1**	**3,699·2**	**60,734·0**
1,978·3	**1,814·6**	**1,967·7**	**2,043·5**	**2,133·7**	**1,994·0**	**1,544·9**	**1,906·7**	**1,966·4**	**1,308·3**	**21,556·7**
1,442·3	**2,544·0**	**1,565·5**	**3,110·9**	**4,788·8**	**1,962·8**	**119·7**	**323·9**	**913·7**	**1,017·9**	**21,026·6**
28·7	5·2	—	1·2	23·6	1·1	—	·4	59·3	3·4	**397·0**
382·1	484·0	544·7	561·4	631·2	331·9	362·2	749·8	323·1	251·0	**4,730·8**
45·4	64·2	68·5	60·4	86·2	49·8	53·4	39·6	160·9	189·2	**873·0**
344·6	412·0	475·9	529·6	470·4	367·5	307·2	311·6	342·2	232·0	**4,044·3**
54·6	85·2	97·7	113·0	175·6	133·1	94·0	351·0	203·4	122·8	**1,491·0**
27·4	23·3	8·0	—	—	—	—	—	—	—	**58·7**
—	—	93·4	135·7	188·2	163·6	20·4	10·7	10·8	21·9	**644·7**
115·5	72·8	—	—	—	—	—	—	—	—	**342·4**
10·8	—	—	—	—	—	—	—	—	—	**23·3**
17·5	1·0	—	—	—	—	—	—	—	—	**40·5**
87·8	5·2	16·0	—	—	—	—	—	—	—	**171·8**
10·8	28·6	9·9	—	—	—	—	—	—	—	**49·3**
614·8	547·1	509·8	530·8	494·0	368·6	307·2	312·0	401·5	235·4	**5,063·5**
447·5	569·2	735·8	810·1	995·0	628·6	476·6	1,111·5	537·3	395·7	**6,889·8**
62·9	65·2	68·5	60·4	86·2	49·8	53·4	39·6	160·9	189·2	**913·5**
1,125·2	1,181·5	1,314·1	1,401·3	1,575·2	1,047·0	837·2	1,463·1	1,099·7	820·3	**12,866·8**

[3] Viz., 6-pdr., 12-pdr. (12 cwt.), H.E., S., and Incendiary, 13-pdr. (6 cwt.), H.E., S., and Incendiary, 13-pdr. (9 cwt.), H.E., S., Incendiary, and Star, 3-in. (5 cwt.), H.E. and Incendiary, 3-in. (20 cwt.) H.E., S., Incendiary, and Star, 18-pdr., H.E., S., and Incendiary, A.Z., and 4-in. H.E.

[4] Viz., 13-pdr. (9 cwt.), H.E., 3-in. (20 cwt.), H.E., and 18-pdr. H.E. [5] Viz., 3-in. (20 cwt.) H.E.

SHELL-FILLING

(Figures in Thousands.)

		1914.	1915.				1916.	
		1 Aug. to 31 Dec.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr	2nd Qtr.
MEDIUM (Category II)—*contd.*								
B.—Field Howitzer Amn.—								
4·5-in. H.E.	O.F.	27·6	41·7	42·7	163·7	329·6	452·3	650·7
	N.F.F.	—	—	—	—	—	6·5	451·8
	Trade	—	—	—	—	21·2	110·8	447·4
S.	O.F.	34·1	22·8	37·2	90·7	44·2	76·2	44·5
	N.F.F.	—	—	—	—	—	·1	16·3
Chemical	O.F.	—	—	—	—	—	—	—
	N.F.F.	—	—	—	—	—	—	—
Smoke	N.F.F.	—	—	—	—	—	—	—
Incendiary	O.F.	—	—	—	—	—	—	1·0
5-in. H.E.	O.F.	—	—	2·5	20·0	76·5	5·5	35·1
	N.F.F.	—	—	—	—	—	—	—
	Trade	—	—	—	—	—	12·7	—
S.	O.F.	·9	·3	5·8	5·1	3·3	1·3	·5
Total ..	O.F.	62·6	64·8	88·2	279·5	453·6	535·3	731·8
	N.F.F.	—	—	—	—	—	6·6	468·1
	Trade	—	—	—	—	21·2	123·5	447·4
Total ..	..	62·6	64·8	88·2	279·5	474·8	665·4	1,647·3
Total (Medium) ..	**O.F.**	**105·5**	**122·6**	**160·9**	**405·8**	**542·0**	**710·5**	**910·8**
	N.F.F.	—	—	—	—	—	**9·8**	**647·4**
	Trade	—	—	—	**1·5**	**27·4**	**147·8**	[illegible]
HEAVY (Category III)—								
A.—Gun Amn.—								
6-in. H.E.	O.F.	4·8	4·9	16·7	25·2	3·5	44·1	53·5
	N.F.F.	—	—	—	—	—	—	—
A.P.	O.F.	—	—	—	—	—	—	3·1
S.	O.F.	·1	—	—	·1	—	4·0	7·3
	N.F.F.	—	—	—	—	—	—	—
Total ..	O.F.	4·9	4·9	16·7	25·3	3·5	48·1	63·9
	N.F.F.	—	—	—	—	—	—	—
Total ..	..	4·9	4·9	16·7	25·3	3·5	48·1	63·9
B.—Howitzer Amn.—								
6-in. H.E.	N.F.F.	—	—	—	—	—	—	177·0
	Trade	—	—	—	37·7	67·9	44·6	98·5
Chemical	N.F.F.	—	—	—	—	—	—	—
Star	O.F.	—	—	—	—	—	—	—
Total ..	O.F.	—	—	—	—	—	—	—
	N.F.F.	—	—	—	—	—	—	177·0
	Trade	—	—	—	37·7	67·9	44·6	98·5
Total ..	..	—	—	—	37·7	67·9	44·6	[illegible]
Total (Heavy) ..	**O.F.**	**4·9**	**4·9**	**16·7**	**25·3**	**3·5**	**48·1**	[illegible]
	N.F.F.	—	—	—	—	—	—	[illegible]
	Trade	—	—	—	**37·7**	**67·9**	**44·6**	[illegible]
VERY HEAVY (Category IV)—								
A.—Gun Amn.—								
9·2-in. H.E.	O.F.	1·5	·1	1·6	1·4	1·9	·5	·3
	N.F.F.	—	—	—	—	—	—	—
A.P.	O.F.	—	—	—	—	—	·7	—
S.	O.F.	—	·9	·2	·5	1·4	—	—
12-in. H.E.	O.F.	—	—	—	—	—	—	—
S.	O.F.	—	—	—	—	—	—	—
Total ..	O.F.	1·5	1·0	1·8	1·9	3·3	1·2	·3
	N.F.F.	—	—	—	—	—	—	—
Total ..	..	1·5	1·0	1·8	1·9	3·3	1·2	·3

—continued.

(Figures in Thousands.)

1916.		1917.				1918.				Total.
3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	
451·3	679·0	699·7	593·5	615·9	567·4	419·4	389·5	489·6	250·6	**6,864·2**
1,902·0	2,178·9	2,360·1	2,470·8	2,188·6	2,413·4	2,032·7	2,319·4	1,876·2	1,002·9	**21,203·3**
372·4	217·6	230·5	232·0	214·7	206·5	199·9	1·6	—	—	**2,254·6**
12·4	—	3·0	—	—	—	—	—	—	—	**365·1**
—	—	—	15·6	—	—	—	—	—	—	**32·0**
77·6	70·5	66·0	—	—	—	—	—	—	—	**214·1**
—	18·0	110·0	321·1	351·4	172·2	222·9	329·8	478·7	199·3	**2,203·4**
—	—	—	28·5	40·8	49·2	82·9	62·9	102·7	100·7	**467·7**
15·5	9·3	—	—	—	·3	·7	1·3	·1	·3	**28·5**
54·7	26·7	1·6	—	—	—	—	—	—	—	**222·6**
—	—	4·8	34·6	68·7	17·5	—	—	—	—	**125·6**
—	—	—	—	—	—	—	—	—	—	**12·7**
·1	—	—	—	—	—	—	—	—	—	**17·3**
611·6	785·5	770·3	593·5	615·9	567·7	420·1	390·8	489·7	250·9	**7,711·8**
1,902·0	2,196·9	2,474·9	2,870·6	2,649·5	2,652·3	2,338·5	2,712·1	2,457·6	1,302·9	**24,032·0**
372·4	217·6	230·5	232·0	214·7	206·5	199·9	1·6	—	—	**2,267·3**
2,886·0	3,200·0	3,475·7	3,696·1	3,480·1	3,426·5	2,958·5	3,104·5	2,947·3	1,553·8	**34,011·1**
1,226·4	**1,332·6**	**1,280·1**	**1,124·3**	**1,109·9**	**936·3**	**727·3**	**702·8**	**891·2**	**486·3**	**12,775·3**
2,349·5	**2,766·1**	**3,210·7**	**3,680·7**	**3,644·5**	**3,280·9**	**2,815·1**	**3,823·6**	**2,994·9**	**1,698·6**	**30,921·8**
435·3	**282·8**	**299·0**	**292·4**	**300·9**	**256·3**	**253·3**	**41·2**	**160·9**	**189·2**	**3,180·8**
79·3	65·2	82·5	60·6	69·1	15·3	56·4	64·2	27·8	16·7	**689·8**
—	—	—	—	—	27·2	43·0	70·8	67·6	46·3	**254·9**
2·0	—	3·0	1·3	—	—	—	—	—	—	**9·4**
16·4	5·3	38·2	57·4	72·4	45·3	41·8	68·0	71·9	80·0	**508·2**
—	—	—	—	—	—	—	25·9	43·1	35·8	**104·8**
97·7	70·5	123·7	119·3	141·5	60·6	98·2	132·2	99·7	96·7	**1,207·4**
—	—	—	—	—	27·2	43·0	96·7	110·7	82·1	**359·7**
97·7	70·5	123·7	119·3	141·5	87·8	141·2	228·9	210·4	178·8	**1,567·1**
636·5	1,364·8	1,743·3	2,263·5	3,695·8	2,593·0	2,549·9	3,183·9	4,038·2	2,336·3	**24,582·2**
188·0	135·2	137·1	93·7	65·5	59·6	66·9	30·6	56·2	44·9	**1,126·4**
—	—	—	—	—	49·8	169·7	361·8	512·4	265·1	**1,358·8**
—	—	—	—	—	—	·5	1·4	1·6	3·2	**6·7**
—	—	—	—	—	—	·5	1·4	1·6	3·2	**6·7**
636·5	1,364·8	1,743·3	2,263·5	3,695·8	2,642·8	2,719·6	3,545·7	4,550·6	2,601·4	**25,941·0**
188·0	135·2	137·1	93·7	65·5	59·6	66·9	30·6	56·2	44·9	**1,126·4**
824·5	1,500·0	1,880·4	2,357·2	3,761·3	2,702·4	2,787·0	3,577·7	4,608·4	2,649·5	**27,074·1**
97·7	**70·5**	**123·7**	**119·3**	**141·5**	**60·6**	**98·7**	**133·6**	**101·3**	**99·9**	**1,214·1**
636·5	**1,364·8**	**1,743·3**	**2,263·5**	**3,695·8**	**2,670·0**	**2,762·6**	**3,642·4**	**4,661·8**	**2,688·5**	**26,800·7**
188·0	**135·2**	**137·1**	**93·7**	**65·5**	**59·6**	**66·9**	**30·6**	**56·2**	**44·9**	**1,126·4**
3·6	2·0	2·7	3·7	5·3	5·4	2·0	3·8	11·5	8·2	**55·5**
—	—	—	—	—	—	—	6·0	2·7	—	**8·7**
—	—	·7	1·2	1·2	1·3	·3	·5	—	·3	**6·2**
—	—	·3	·4	1·1	1·2	·6	·7	1·2	·9	**9·4**
—	—	·2	1·2	1·2	1·3	·8	—	1·3	—	**6·0**
—	—	—	·1	·3	·3	·2	·2	—	—	**1·1**
3·6	2·0	3·9	6·6	9·1	9·5	3·9	5·2	14·0	9·4	**78·2**
—	—	—	—	—	—	—	6·0	2·7	—	**8·7**
3·6	2·0	3·9	6·6	9·1	9·5	3·9	11·2	16·7	9·4	**86·9**

SHELL-FILLING

(Figures in Thousands.)

		1914.	1915.				1916.	
		1 Aug. to 31 Dec.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.
VERY HEAVY (Category IV)—*cont.*								
B.—Howitzer Amn.—								
8-in. H.E.	O.F.	—	—	1·8	10·1	12·8	3·0	—
	N.F.F.	—	—	—	—	—	—	25·6
	Trade	—	—	—	—	19·5	36·3	42·6
9·2-in. H.E.	O.F.	·2	2·6	5·1	8·8	11·6	15·8	21·2
	N.F.F.	—	—	—	—	—	—	32·5
	Trade	—	—	—	·3	3·3	7·1	10·5
12-in. H.E.	O.F.	—	—	—	·6	2·3	2·1	·1
	N.F.F.	—	—	—	—	—	·1	6·2
	Trade	—	—	—	—	—	3·7	2·6
15-in. H.E.	O.F.	—	—	—	—	—	·7	2·2
	N.F.F.	—	—	—	—	—	—	—
Total ..	O.F.	·2	2·6	6·9	19·5	26·7	21·6	23·5
	N.F.F.	—	—	—	—	—	·1	64·3
	Trade	—	—	—	·3	22·8	47·1	55·7
Total ..	..	·2	2·6	6·9	19·8	49·5	68·8	143·5
Total (Very Heavy)	**O.F.**	**1·7**	**3·6**	**8·7**	**21·4**	**30·0**	**22·8**	**23·8**
	N.F.F.	—	—	—	—	—	**·1**	**64·3**
	Trade	—	—	—	**·3**	**22·8**	**47·1**	**55·7**
Grand Total ..	**O.F.**	**527·8**	**592·7**	**961·3**	**1,411·8**	**2,039·7**	**2,394·9**	**3,200·5**
	N.F.F.	—	—	—	—	**73·6**	**201·8**	**3,217·3**
	Trade	—	—	—	**199·5**	**660·4**	**1,110·2**	**1,977·6**
TOTAL	**Home**	**527·8**	**592·7**	**961·3**	**1,611·3**	**2,773·7**	**3,706·9**	**8,395·4**
	Abroad	—	—	**225·0**	**561·1**	**701·2**	**629·9**	**1,119·9**
GRAND TOTAL ..	..	**527·8**	**592·7**	**1,186·3**	**2,172·4**	**3,474·9**	**4,336·8**	**9,515·3**

(c) Propellant Consumption.

While the number of rounds delivered from the filling factories denotes one aspect of the Ministry's achievement, it does not provide an exact index to variations in the amount of the work which the factories did. It varied with H.E., shrapnel, chemical, or incendiary shell, each of which passed through entirely different operations in the filling and assembling factories. A more reliable common measure of the volume of work done in the aggregate lies in the quantities of propellant used; for every shell that was issued had to be provided with its corresponding cartridge or cartridges, whether it was sent out as a fixed round as was the Q.F. ammunition, or separately as was the B.L. ammunition. Moreover, the weight of the propellant corresponded to a certain degree with the weight of the shell. The following table showing month by month the average weekly rate of propellant consumption gives a fair idea of the fluctuations in the work of the filling and assembling factories, from the beginning of 1916, when the new national factories began to come into action. It will be seen that the rate of completion rose steadily until October, 1916. There followed a slackening during the winter months. From February, 1917, till the following October the factories worked at high pressure, attaining their record rate during July, in the middle of the summer campaign. The

—continued.

(Figures in Thousands.)

1916.		1917.				1918.				Total.
3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	
18·3	18·3	66·4	123·6	101·9	59·7	8·4	—	—	1·4	**425·7**
211·0	327·5	486·6	320·0	518·3	828·9	653·6	312·3	587·2	314·1	**4,585·1**
77·4	100·0	99·7	34·5	—	—	—	—	21·4	21·1	**452·5**
49·6	29·5	16·9	—	—	—	—	—	—	—	**161·3**
262·6	411·3	514·2	372·1	301·1	377·5	373·7	187·2	252·4	216·6	**3,301·2**
29·6	41·1	32·8	26·4	36·9	45·2	24·0	8·2	—	—	**265·4**
7·8	4·4	1·1	2·5	5·4	6·2	3·5	—	—	—	**36·0**
25·1	17·9	13·4	10·3	18·4	53·4	27·4	7·4	30·1	8·6	**218·3**
5·9	6·7	7·1	2·7	—	—	—	—	—	—	**28·7**
1·8	1·8	1·7	1·1	3·0	2·5	·4	—	—	—	**15·2**
·1	1·0	1·0	1·1	1·5	2·3	2·5	2·0	·6	—	**12·1**
77·5	54·0	86·1	127·2	110·3	68·4	12·3	—	—	1·4	**638·2**
498·8	757·7	1,015·2	703·5	839·3	1,262·1	1,057·2	508·9	870·3	539·3	**8,116·7**
112·9	147·8	139·6	63·6	36·9	45·2	24·0	8·2	21·4	21·1	**746·6**
689·2	959·5	1,240·9	894·3	986·5	1,375·7	1,093·5	517·1	891·7	561·8	**9,501·5**
81·1	**56·0**	**90·0**	**133·8**	**119·4**	**77·9**	**16·2**	**5·2**	**14·0**	**10·8**	716·4
498·8	**757·7**	**1,015·2**	**703·5**	**839·3**	**1,262·1**	**1,057·2**	**514·9**	**873·0**	**539·3**	8,125·4
112·9	**147·8**	**139·6**	**63·6**	**36·9**	**45·2**	**24·0**	**8·2**	**21·4**	**21·1**	746·6
3,801·1	**3,797·7**	**4,295·0**	**4,125·3**	**3,671·2**	**3,295·8**	**2,850·5**	**2,461·6**	**2,538·5**	**1356·9**	**43,322·3**
8,902·6	**12,166·3**	**14,189·9**	**14,194·1**	**12,127·5**	**10,421·2**	**10,072·8**	**15,494·9**	**16,399·3**	**8,620·6**	**126,081·9**
2,709·5	**2,380·4**	**2 543·4**	**2,493·2**	**2,537·0**	**2,355·1**	**1,889·1**	**1,966·7**	**2,204·9**	**1,563·5**	**26,610·5**
15,413·2	**18,344·4**	**21,028·3**	**20,812·6**	**18,335·7**	**16,072·1**	**14,812·4**	**19,943·2**	**21,142·7**	**11,541·0**	**196,014·7**
1,442·3	**2,544·0**	**1,565·5**	**3,110·9**	**4,788·8**	**1,962·8**	**119·7**	**323·9**	**913·7**	**1,017·9**	**21,026·6**
16,855·5	**20,888·4**	**22,593·8**	**23,923·5**	**23,124·5**	**18,034·9**	**14,932·1**	**20,267·1**	**22,056·4**	**12,558·9**	**217,041·3**

reduction for the winter of 1917-1918 was considerable, but did not fall to the level of the previous winter, and the rate attained during 1918 exceeded any previous record. The July figure was greater than that of the previous year, and the final effort for victory is reflected in the highest rate of all, which was attained during October, 1918.

TABLE SHOWING THE AVERAGE WEEKLY CONSUMPTION OF PROPELLANTS—1916–1918.[1]

	1916. Tons.	1917. Tons.	1918. Tons.
January	320	1,898	2,515
February	457	2,603	2,572
March	537	2,847	2,353
April	607	2,702	2,860
May	804	2,434	2,800
June	800	2,498	3,169
July	1,496	3,385	3,460
August	1,861	3,025	3,308
September	1,948	3,035	3,074
October	1,902	3,066	3,594
November	1,864	2,712	—
December	1,526	2,024	—

[1] The figures denote the number of tons (2,000 lb.) of cannon cordite and nitro-cellulose powder consumed weekly in the home production of cartridges.

II. Components.

The importance of maintaining a regular proportionate flow of fuses, cartridges and other components has already been emphasized.[1] Certain classes of these, such as detonators and fuses, had a peace-time use, chiefly in the mining industry, and contractors were more ready to fill these than shell. Moreover, the trade was willing to execute such orders at relatively cheap rates, doubtless with a view to maintaining their peace-time capacity. This was particularly the case with detonator production.

(*a*) Fuses.

The table which follows shows the output of filled fuses yearly throughout the war, specifying the place of filling. While large quantities of empty percussion fuses were drawn from Switzerland, the importation of filled fuses was restricted to time and percussion fuses of American origin. Dependence upon this source of supply was greatest in the year 1916, when importations made up four-ninths of the supplies of this class of fuse. By 1918 this proportion had been reduced to about one-third. The manufacture of T. and P. fuses was the more familiar to the trade, and throughout the war an overwhelming proportion of this class of fuse was obtained from contractors. Out of some 100,000,000 T. and P. fuses produced between August, 1914, and December, 1918, the trade filled nearly 65,000,000 and American-filled fuses accounted for another 35,000,000. It was in the filling of percussion fuses that the activity of State factories was greatest. By December, 1915, the Ordnance Factories and the trade between them had produced rather more than 2,000,000 percussion fuses, of which the trade filled about a quarter. In 1916 the National Filling Factories outstripped the Ordnance Factories in this work, although the output from these had enormously increased. In the end the total number of percussion fuses filled during the war reached nearly 147,000,000, of which the new National Filling Factories dealt with nearly 78,000,000 and the Ordnance Factories with over 47,000,000.

During the first eighteen months of war the fuses filled numbered 7,555,900. During the year 1916 this figure was 63,307,100. In 1917, when the policy of laying up stocks of components was in full force, the fuses which were filled numbered 102,346,500. In 1918 there was a general reduction in the filling of all classes of fuse. The aggregate for the whole of the war was 248,886,900. The National Filling Factories were responsible for approximately 37 per cent., the trade for 35 per cent., and the Ordnance Factories for 28 per cent. of this total.

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[1] See above, Chap. V.

OUTPUT OF FILLED FUSES.

(Figures denote thousands.)

Fuses.	Aug, 1914 to Dec. 1915.	1916.	1917.	1918.	Total.
Percussion.					
O.F.	1,671·4	13,813·1	19,288·3	12,698·5	47,471·3
N.F.F.	—	16,905·6	33,438·9	27,314·6	77,659·1
Trade	535·6	4,540·2	7,645·8	8,776·6	21,498·2
Total Percussion (Home)	2,207·0	35,258·9	60,373·0	48,789·7	146,628·6
Time and Percussion or Time.					
O.F.	650·2	1,908·5	4,295·3	2,769·5	9,623·5
N.F.F.	9·9	—	1,722·4	393·9	2,126·2
Trade	2,988·8	12,997·4	20,918·8	16,085·8	52,990·8
Total Home	3,648·9	14,905·9	26,936·5	19,249·2	64,740·5
Abroad	1,700·0	12,875·3	14,395·5	6,591·2	35,562·0
Total T. and P. or Time	5,348·9	27,781·2	41,332·0	25,840·4	100,302·5
Base Fuses.					
O.F.	—	267·0	641·5	1,033·1	1,941·6
N.F.F.	—	—	—	14·2	14·2
Total Base Fuses ..	—	267·0	641·5	1,047·3	1,955·8
Total Fuses	7,555·9	63,307·1	102,346·5	75,677·4	248,886·9

(*b*) CARTRIDGE CASES.

The filling and assembling of fuses is work of a highly complex character, which, because of its intricacy and limited output, was at several stages of the war the decisive governing factor in the supply of ammunition. It would be impracticable to give in similar detail the enormous numbers of other components which were supplied during the war. The following table of output of filled cartridge cases will serve, however, to illustrate the yearly output of one important class, *viz.*, the cartridges needed for fixed ammunition only.

Output of Filled Cartridge Cases.

(Figures denote thousands.)

	1914.	1915.	1916.	1917.	1918.	Total.
18-pdr. Cartridge Cases—						
Home ..	350·8	3,828·8	27,398·0	37,846·8	37,623·2	107,047·6
Abroad ..	—	1,487·3	5,735·4	11,001·0	2,375·2	20,598·9
Total, 18-pdr.	350·8	5,316·1	33,133·4	48,847·8	39,998·4	127,646·5
4·5-in. Cartridge Cases Total (Home)	61·7	793·8	8,262·1	13,951·0	10,563·9	33,632·5
13-pdr. (6 cwt.) Cases						
Home ..	40·6	335·7	709·5	568·8	571·1	2,226·0
Abroad ..	—	—	—	427·0	—	427·0
Total 13-pdr. (6 cwt.) ..	40·6	335·7	709·5	995·8	571·1	2,653·0
Total 13-pdr. (9 cwt.) Home	—	—	812·3	1,573·7	1,467·4	3,853·4
Total 3-in. Home	2·6	3·9	238·3	446·9	615·0	1,306·7
Total 3·7-in. Home ..	—	—	—	54·5	83·9	138·4
Total 12-pdr. Home ..	—	—	29·1	28·5	6·0	63·6
Total Home	455·7	4,962·2	37,449·6	54,470·2	50,930·5	148,268·2
,, Abroad	—	1,487·3	5,735·4	11,428·0	2,375·2	21,025·9
Grand Total ..	455·7	6,449·5	43,185·0	65,898·2	53,305·7	169,294·1

Of the aggregate of 169,000,000 cartridge cases which were filled 21,000,000 only came from abroad, with complete rounds of ammunition, and the remainder were filled at home.

These tables are illustrative only. They will have served their purpose by giving some measure by which to judge of the size and variety of the task undertaken in completing some 217,000,000 rounds of gun ammunition for the use of British troops during the war.

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VOLUME X

THE SUPPLY OF MUNITIONS

PART VI

ANTI-AIRCRAFT SUPPLIES

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CHAPTER I.

TECHNICAL INTRODUCTION.

I. The Problems of Anti-Aircraft Gunnery.

The anti-aircraft supplies dealt with in this section are mainly those employed in attacking hostile aircraft by means of artillery on the ground; attacks on aircraft by aircraft are treated more properly in the section on aeronautics. Some of the weapons used, such as searchlights and incendiary projectiles, play a part in both methods of attack, but the problems which are concerned here are chiefly those of gunnery.

The chief problems of all forms of gunnery are three: the determination of the position and motion of the target relative to the gun; the subsequent determination of the direction in which the gun should be pointed in order that the projectile may hit the target; and the bursting of the projectile so that it may do the greatest amount of damage to the target. This last problem does not arise when a plain solid projectile is used, but such projectiles are almost obsolete in any gun larger than a rifle or machine gun. In respect of each of these problems, anti-aircraft work introduced difficulties which are absent or much less important in naval or military gunnery of the older type.

These difficulties arise mainly from the very rapid and variable motion of the target. The older methods of military and naval gunnery were based on the assumption that the position and velocity of the target does not change greatly during the period of a minute or more which is necessary to calculate from the observations how the weapon should be used. It was usual to correct the results of these calculations from the results of trial shots. These methods are quite inapplicable in anti-aircraft gunnery, for the whole time that the target is within range may not be greater than that required by these methods for the firing of the first shot. It is essential that the calculations on which the use of the weapon is based should be performed almost instantaneously as soon as the target comes into sight; this condition implies that the calculations shall be performed almost automatically, and with the very least possible dependence upon any kind of thought or reasoning.

In addition to this main difficulty there are three minor differences between anti-aircraft and other forms of gunnery. (1) While in naval or military gunnery the object is always known to lie in or very close to the horizontal plane which contains the gun, this limitation is not imposed on aircraft. In geometrical language, the position of naval

and land targets has to be determined in two dimensions only; that of aircraft has to be determined in three dimensions.

In Section VIII. it will be seen also that the mere height of the target above the earth introduces some special problems.

(2) The target is often invisible. Naval and military guns sometimes fire at invisible targets, but almost only when the position of the target can be determined by a map. But anti-aircraft guns have to attack rapidly moving targets at night, or when the target is concealed by ground mists; and even in the daytime with no actual mists it is often difficult to pick up the target by eye with sufficient quickness to enable it to be attacked before it passes out of range. Some method of location independent of sight is therefore desirable.

(3) A fourth difference, sometimes practically important, is that in anti-aircraft gunnery it is more usual for several guns separated by considerable distances to fire at the same target.

The three problems of gunnery will now be considered in turn. The first is that of determining the position of the target.

II. Height- and Range-Finders.

If the target were stationary, and if the projectile travelled in a straight line, then the direction of the target as seen from the gun would be the direction in which the gun had to be pointed. But since the projectile is falling along the whole of its path the gun has to be pointed somewhat above the line of sight in order to allow for this fall; the angle between the proper direction of the gun and the line of sight (the target being stationary and there being no wind) is called the tangent elevation (T.E.). The familiar sliding sight of a rifle, which ensures that the barrel shall be pointed above the line of sight, is a simple device for securing the correct T.E. The T.E. increases with the "range" of the target, *i.e.*, its distance from the gun, a fact which is again familiar from the sight of a rifle. Accordingly, in all forms of gunnery, the determination of the range is one of the first necessities for accurate shooting, in order that the gun may be given the correct T.E.

All the most accurate range-finders make use of the principle illustrated by this diagram:—

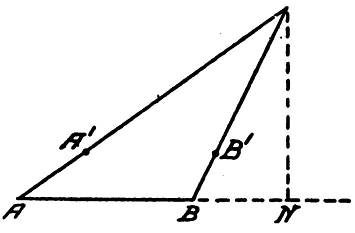

Fig. 1.

A and B are two observers at the ends of a base AB, the length of which is known, P is the target. If A and B determine the angles PAB and PBA, then from a knowledge of these angles and of the length of the base the range PA or PB can be calculated. The accuracy of the result depends partly on the accuracy of the determination of the angles, partly on the ratio of the base AB to the range PA; the greater this ratio the greater the accuracy. A range-finder consists, therefore, essentially of (1) a measured base AB, (2) instruments for determining the angles PAB and PBA, (3) some device for calculating the range accurately when the angles are known. The ingenious methods by which this principle is carried into effect do not concern us here, for simple range-finders of this kind are not used in anti-aircraft work; but it may be noted that the accuracy in the determination of the angles is such that, with a base of no more than 30 ft., ranges up to many miles can be determined with all the accuracy required for naval warfare. For the shorter ranges at which field guns fire a base of a few feet is often sufficient, and the instrument can be made in a compact form, portable and usable by one man.

However, the T.E. for a given gun does not depend only on the range; it depends also on the "angle of sight," which is the angle, measured in a vertical plane, between the line of sight and the horizontal. That there must be a dependence of this kind is easily seen by considering a target vertically over the gun, so that the angle of sight is a right angle. Then, since gravity acts along the line of sight, it does not tend to deflect the projectile from that line, but only decreases its speed: accordingly the T.E. is 0, and the gun ought to be pointed along the line of sight. The relation between the T.E. and the angle of sight is complicated and varies with the gun used, but in general the T.E. decreases as the angle of sight is increased. In naval or military gunnery, since the angle of sight is never very different from 0, it is almost unnecessary to consider this variation at all: a rifle sighted correctly for an object in the same horizontal plane as the firer will be sighted correctly for any object at the same range at which the rifle was likely to be fired before aircraft became important. But aircraft which it is desired to attack from the ground with a rifle or gun are, of course, often at great distances above the ground, and the angle of sight is quite as likely to be 90 deg. as 0, and quite as likely to be anything between the two. Accordingly it is necessary, in order to know the correct T.E., to know the angle of sight as well as the range.

There is no difficulty in determining the angle of sight; we have merely to fix to the sight, or to the gun to which the sight is fixed, a pointer moving over a vertical scale graduated in angles, and to read off on this scale the angle when the sight is pointed at the target. As a matter of fact, such a scale is always fitted for the purpose of determining the angle to the horizontal at which the gun should be pointed. This angle is called the quadrant elevation (Q.E.). It should be noted that, if the target is motionless and in the same horizontal plane as the gun, the Q.E. is the same thing as the T.E.; but if it is not, the Q.E. is the sum of the angle of sight, the T.E., and

the "vertical deflection" (to be discussed presently) necessary to allow for the motion of the target. To obtain the information necessary to determine the T.E. when the angle of sight is not 0, nothing but a simple modification of existing appliances is absolutely necessary.

But now new considerations enter. We have seen that in order to determine how the gun should be pointed a knowledge of the range and angle of sight is required. From these two quantities the height of the target above the ground can easily be calculated. Thus in Fig. 1, if the length PA and the angle PAB are known (AB being supposed horizontal), the height PN is known. Conversely, if the height and the angle of sight are known, the range can be calculated; so that a knowledge of the height will suffice instead of a knowledge of the range. There are considerable advantages in anti-aircraft gunnery in determining the height rather than the range. First, the range of the target from any gun is usually changing rapidly, but since aircraft generally keep a level course, except when they are attacking or attacked, the height is nearly constant. If there is any delay, as there must be, between measuring the range and communicating it to the gunner, the information he receives may be practically useless because the range will have changed greatly in the interval. On the other hand, the height may remain constant for minutes together, and a knowledge of the height a few seconds earlier will be as valuable as a knowledge of the height at the actual moment of firing. Second, the height is the same for all the guns firing at the target so long as they are approximately on the level; a single determination of the height by a single instrument will serve all the guns alike, while each gun would require its own range-finder.[1]

These considerations led to the replacement of the range-finders usual in other forms of gunnery by height-finders.[2] Two principles were employed in these instruments. The first, represented in the Barr and Stroud Height Finder, was essentially the calculation of the height from the range and angle of sight. A Barr and Stroud Range Finder with a base of two metres was combined with a scale for measuring angle of sight; a mechanical arrangement of gear wheels and cams calculated the height from these quantities and, moreover, insured that, so long as the height remained constant, the instrument required no adjustment although the range and angle of sight altered. The instrument is very ingenious and preserves nearly the full accuracy of the range-finder; with a base of only 6 ft. heights of many thousand feet could be measured with all the accuracy required. But it was expensive and elaborate and did not come into general use.

The second principle was suggested independently in January, 1916, by Mr. G. T. Bennett, F.R.S., and Lieut. J. M. Mansell-Pleydell;

[1] This statement is not strictly accurate. If the distance of the guns from each other is known, the range determined for three of them enables the range from any other to be calculated. But at least three range-finders would be required, the calculations would take time and would be upset if it were necessary to move any of the guns.

[2] A pamphlet on A.A. range- and height-finders was published by M.I.D.

it was also discovered in France at about the same time. It is generally known as the Bennett principle. It is also illustrated by Fig. 1,[1] if it is now supposed that PA and PB are the traces where planes perpendicular to the paper cut the plane of the paper; these planes rotate about lines perpendicular to the paper and cutting it in A and B. P is not the actual target (unless this happens to lie in the plane of the paper), but the point at which the horizontal line which passes through the target and in which the planes PA and PB meet cuts the plane of the paper. PN is then the height of the target above the base; and it will be seen again that a knowledge of the angles PAB, PBA and of the length of the base AB is sufficient to determine PN.

The principle is perhaps better shown in Fig. 2, which shows the planes in perspective (the angles which they make with the base being different from those of Fig. 1). Here AC, BD are the axes about which the planes turn, PP^1 the line in which they intersect, T the actual target.

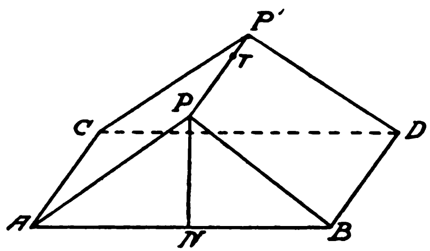

FIG. 2.

This principle is applied in several distinct ways. In one way (which is employed in the Rayner and Paterson-Walsh height-finders) the planes PA and PB (Fig. 1) are represented by rigid frames hinged about the lines A and B. Each of these frames carry two long slits at A and C or B and D, these slits being parallel to A or B. The observer rotates the plane round A or B until he can see the target through both slits; he then knows that the target lies in the prolongation of the plane AC or BD; he reads off the angle PAB or PBA on a scale and a calculator to whom the angles are communicated calculates the height from the angles and the fixed base.

The calculation by trigonometrical methods would be far too slow to be serviceable; accordingly it is performed by means of an instrument which is essentially a small scale model of the height finder. There are arms, corresponding to PA, PB, rotating round pins at A and B over a board ruled with horizontal lines. The scale represented by these lines is such that, on this scale, AB is the length of the base. If, then, the angles PAB, PBA, are set to those observed, PN, read on the scale of the horizontal lines will be the height. This is the method adopted in the Rayner height-finder.

[1] See above, p. 2.

Many electrical devices were suggested for combining into a single automatic operation the communication of the angles at the two ends of the base and their combination to give the height. But only one of them was embodied in an article of store, namely, the Paterson-Walsh system. This may be described briefly by saying that voltages, determined by the angles and such that their difference is a measure of the height, were caused to act on a voltmeter suitably graduated, which then read the height direct. The observers had then only to keep the target in the planes of a Rayner instrument and the height could be read directly off the voltmeter placed at any convenient position near the guns.

In another application of the principle, for which a new diagram is needed, there are no moving frames. (The Hartree instrument and the French Altimètre à Fil are examples.)

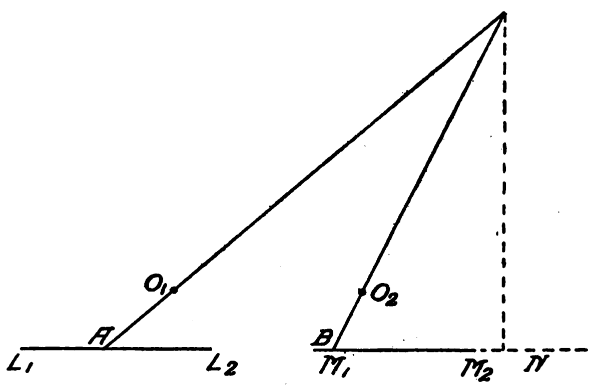

Fig. 3.

In the line of the base and at the observing stations are placed two graduated bars, L_1 L_2, M_1 M_2. They carry pointers sliding along the bars. O_1 and O_2 are wires stretched horizontal and perpendicular to the paper which they cut at O_1 and O_2. Each observer keeps his eye so that the target is covered by the wire and moves the pointer on his bar so that this pointer also covers the target. Then, if the pointers are at A and B, the target must lie in the planes PAO_1, PBO_2, perpendicular to the paper; the height PN is determined, as before, by the angles PAB, PBA and the base AB (the bars L_1 L_2 and M_1 M_2 are so small a fraction of the whole base that AB may be taken to be always equal to L_1 M_1 or L_2 M_2). To every angle PAB or PBA corresponds one, and only one, position of the pointer A or B. Consequently the positions of the pointers give the angles, and from these angles the height can be calculated as before.

But it so happens that the height can be calculated very simply and directly from the lengths measured along the scales L_1 L_2, M_1 M_2, without introducing the angles at all. It is one of the advantages

of the Hartree principle that the calculation of the height from the observed quantities can be performed very rapidly by the use of nothing but simple arithmetic. Accordingly, although both forms of height-finder ultimately depend on the measurements of angles, angles never appear explicitly when the Hartree principle is used as they do when the Bennett principle is used.

Both these forms of height-finder suffer from the disadvantage that the angles PAB and PBA cannot be determined with as great an accuracy as they can with a range-finder. A tenth of a degree is about the limit that can be observed (corresponding to a length of about 3 ft. at a height of 10,000 ft. when the target is directly over the base, and much more than 3 ft. when it is low down on the horizon). Consequently the length of the base has to be very much more than the 3 or 6 ft. which is sufficient with the range-finder ; in order to estimate a height of 12,000 ft. within 300 ft. a base of at least 3,000 ft. has to be employed. Accordingly no simple mechanical device could be adopted for determining the height from angles measured at places so far apart ; some method of communicating the angle at one end of the base to the observer at the other end had to be adopted. Attempts were made to overcome this disadvantage by improving the optical arrangements of the instruments and so enabling the angles to be determined with greater accuracy. Thus a telescope might be fixed so that its axis always lies in the plane PA, but is able to move about in that plane, or mirrors might be used in the manner described in connection with another instrument on p. 3. But the gain in accuracy and the advantage of a shorter base were outweighed by various practical objections, and most of the height-finders that have actually been used on a large scale have been of one of the types that have been described.

Communication between the ends of the base may be effected by telephone. The calculator is at one end of the base and reads directly the angles on the instrument set by the observer in his neighbourhood ; at the same time he receives by telephone the angles on the instrument at the other end of the base ; having made the calculation he communicates the height to the guns by another telephone.

III. Sound Location.

It is an experience familiar to all that the presence of an aeroplane or airship is usually detected in the first instance by the sound that it emits, and that from the sound a rough estimate can be made of the direction in which the aircraft should be looked for. At night it is only by sound that there is any reasonable hope of locating an aeroplane, for even the most complete instalment of searchlights can only cover a very small fraction of the sky and the chance is very small that an aircraft will cross one of the searchlight beams unless these can be purposely turned in the direction in which it is known to lie. Methods of sound location of aircraft are useful even on the clearest and brightest day ; in the dark, when so many air raids took place, they are essential.

Very elaborate and delicate methods of locating objects by sound alone were worked out during the war for detecting submarines and heavy guns on land. These methods with suitable modifications might possibly have been adapted to the detection of aircraft; but as a matter of fact simpler methods were usually sufficient. It was necessary only to obtain an approximate position for the target, in order that searchlights might be directed on it. Once the target was picked up by the searchlights the ordinary optical height-finders and gun-sights could be used to determine its exact position. Location by sound was merely a preliminary to the more accurate location by sight.

For, however perfect may be locating instruments depending on sound, there are two circumstances which make it impossible that they should compete in accuracy with visual methods. First, the speed of an aeroplane may be nearly as great as half the speed of sound. The direction in which the aeroplane is heard is that in which it lies at the instant when the sound which reaches the observer left the aeroplane; this direction may be very different from that in which it lies when the sound reaches the observer. Second, the air is never the clear transparent medium for sound which it is for light on a fine day; hearing through the open air is more like seeing through a pane of ribbed glass; the inequalities of the density of the air bend the rays of sound out of their straight path. Everyone must have noticed how greatly the intensity of the sound from an aeroplane fluctuates; at one moment it is so loud as to force itself on the attention, the next it is barely audible. These fluctuations are due to the irregular and constantly changing refraction of the sound by the air, and the changes in intensity of the sound are accompanied by no less notable changes in its apparent direction. It is easy to construct instruments which will indicate within a small fraction of a degree the direction from which sound is reaching the observer; but even when all possible corrections are applied for the motion of the aeroplane and for the motion of the air as a whole, the direction indicated for the aeroplane may still differ by much more than a degree from its true direction. Nevertheless, the instruments about to be described were invaluable and without them air raids would never have been defeated.

To understand the principle on which they worked it is necessary to ask how it is that with the unaided ears we have a definite sense of the direction of sound. We have such a sense because we have two ears and because we have a very delicate sense of the difference between sounds received at the same time by those two ears. If we turn our head so that we face directly the direction from which the sound is coming then the two ears are disposed quite symmetrically with regard to the sound, and the sound which reaches one ear is exactly the same as that which reaches the other. If, on the other hand, we face at right angles to the direction of the sound, the two ears are not placed symmetrically with regard to it; for one ear is further away from the source than the other by the width of the head, and the head is placed as an obstacle shielding one ear but not the other from the sound. In determining the direction of a sound we instinctively turn our heads so that the

sound received by both ears is the same; we then know that the sound is either directly in front of us or directly behind. (We can distinguish to some degree between these alternatives, but not quite as certainly as is sometimes imagined. The distinction is possible again because of the asymmetry of the head and the external ears in the front to back direction.) Under favourable conditions we can thus fix the direction of a sound within an angle of about five degrees.

Very interesting work by the late Lord Rayleigh has proved that the asymmetry which causes this perception of direction of sound is not due, as might be expected at first sight, to the head acting as an obstacle (except when high notes are heard), but simply to the greater distance of one ear from the source of sound. Owing to the difference in distance, the sound vibrations do not arrive at the two ears in the same phase; that is to say, at the moment when the crest of the wave is impinging on the nearer ear a part somewhat past the crest, and nearer the preceding trough, is impinging on the further ear. It is this difference of phase that is detected by the sensory organ which receives the messages from both external ears and indicates to it that the ears are placed symmetrically with regard to the direction in which the sound is travelling. (How the difference of phase is detected is still an unsolved mystery.)

The phase difference between the sounds arriving at the two ears depends on the difference in the distance which those sounds have travelled in reaching them. Accordingly it would be increased, in any given position of the head, by increasing the distance between the ears. If that distance could be increased, then a phase difference which was too small to be detected (and too small, therefore, to give rise to a sensation of right and left), because the ears were placed very nearly symmetrically with respect to the sound, would be magnified so as to become perceptible. In other words, by increasing the distance between the ears the delicacy of the direct perception of direction of sound would be augmented.

The ears at the normal distance can determine direction within five degrees; if that distance could be increased fifty-fold, the same phase difference would correspond to an angle of one-tenth of a degree, and, in the absence of complicating factors, it should be possible to fix direction within that small angle.

Now the effective distance between the ears can be increased by a very simple device. If we take two trumpets shaped somewhat like gramophone receivers and connect their narrow ends to the two ears by tubing, the effective distance between the ears is the distance apart of the trumpets. That distance can be made as great as we please, but of course difficulties enter if it is made too great; actually it is found that a distance of some five feet between the trumpets is most suitable. The effective distance between the ears is thereby increased about ten times and a tenfold greater accuracy in fixing the direction of the sound can be obtained; indeed, the gain in accuracy is even greater than is to be expected by these very simple considerations.

Such is the principle of the binaural sound locator, developed by the Munitions Inventions Department, which was used almost exclusively for locating aircraft by sound. In the actual instrument two pairs of trumpets are used. One pair, fixed parallel to each other, rotate about a vertical axis. The observer, whose ears are connected by tubes to the trumpets, rotates them, experiencing as he does so the sensation of a very rapid change of the direction of sound from right to left or *vice versa*; he adjusts them so that the source appears directly in front (or behind) him and then knows that the source actually lies in the vertical plane situated symmetrically between the two trumpets. The other pair of trumpets rotate round a horizontal axis, carried by the first pair of trumpets, and both lie in the same vertical plane. A second observer adjusts this pair so that the sound appears directly in front of him; the angle which the direction of sound makes with the horizon is then known and its direction is completely determined.

It has been insisted before that this direction is not necessarily that in which the source lies; corrections have to be applied for the speed of the target, for the wind and for other meteorological conditions. Devices are employed for effecting these conditions automatically, but since they do not differ in principle from those employed with optical locators no mention need be made of them here. The direction finally determined is signalled to the searchlight operators, who then try to direct their beams on the targets.

It is tempting to describe other devices for sound location on which a good deal of experimental work was done under the direction of the Munitions Inventions Department, and with which considerable success was attained. But since these instruments were never produced in quantity and raised none of the problems with which it is the main purpose of this history to deal, they can hardly be considered relevant.

IV. Determination of the Velocity of the Target.

If the target did not move, the instruments that have been considered would tell the gunner all that he required to direct his gun, assuming that he knew the trajectory (see next section). But since the target moves, he has to direct his gun, not at the position where it is when the gun is fired, but at the position where it will be when the projectile reaches it, and for this purpose he requires to know how the target will move in the interval. Of course, if the target is an aeroplane controlled by an intelligent being, he can never *know* how it will move; he can only assume that it will continue to move after the gun has been fired as it was moving just before the gun was fired. And his assumption will very often be wildly wrong. The projectile may take more than 30 seconds to reach the aeroplane; in that time the aeroplane may travel a mile in any direction; it may have turned round completely and started to go home again. Misses that are as good as (and better than) a mile are no reflection on the skill of the gunner.

Nevertheless, aeroplanes, especially when flying in formation and at night, do often keep the same course so long that the assumption is true, and it is worth while to estimate accurately their motion. If the motion is known it can be allowed for by "putting deflection on the gun" in two directions; the gun is moved through an angle (vertical deflection) in the vertical plane containing the line of sight, and an angle (lateral deflection) in a plane perpendicular to this and also containing the line of sight. It is, therefore, convenient to determine the motion in these two planes. Now, of course, the motion could be found by determining the position by means of the range and angle of sight at known intervals before the gun is fired, and calculating the motion from the change of position with the time; but the calculation would be so lengthy and cumbrous that more direct methods are employed. The principle in all of them consists in following the target with two telescopes, one constrained to move in each of the two planes of deflection and measuring the angular velocity of the telescopes. The measurement is effected by means which are familiar in the speedometer of a motor car; the measurement is either mechanical (as in the Wilson-Dalby system) or electrical (as in the more efficient Brocq system). In the first it is made by an instrument essentially similar to the governor of a steam engine; the centrifugal force due to rotation causes the divergence of heavy masses. In the second it is made by an instrument similar to a dynamo—a magneto is actually used—which gives a voltage proportional to the speed of rotation of the armature. There is nothing new or particularly striking in either of these principles, and their application to gunnery is not wholly new, for some instruments for controlling naval fire employ similar devices. Their novel features appear in the manner in which the indications of the instruments are made to determine the deflections of the gun. But any attempt to consider the devices used for this purpose would lead us so far into mechanical detail that no description of them would be suitable in a discussion of general principles.

V. Trajectories.

So far we have only considered how part of the information which the gunner requires is obtained, namely that which concerns the position and motion of the target; we must now proceed to consider how this information is translated into action. Here we arrive at the second problem of gunnery, that of determining, when the position and motion of the target are known, how the gun should be pointed in order to hit it.

To solve this problem, information of a new kind is required. The trajectory of the projectile must be known, that is, the path which it follows after leaving the gun. This information differs from that which we have considered so far, because it can be and must be obtained independently of the presence of the actual target; it depends on the character of the gun rather than of the target. Nevertheless, when a gun which has been used for land and sea targets

is used against aircraft new information is required. For the shape of the trajectory depends not only on the muzzle velocity (M.V.) of the projectile and on its shape, but also on the quadrant elevation at which it is projected. If fired vertically, the projectile travels along a straight line; as the inclination to the horizontal is decreased, the deviation of the path from a straight line at corresponding distances from the gun becomes continually greater. Accordingly, trajectories of projectiles fired at large Q.E.'s, such as are necessary in anti-aircraft gunnery, are quite different from those used in other forms of gunnery; a knowledge of the latter does not always involve a knowledge of the former.

The trajectory of the projectile may be determined by either of two methods. First it may be determined wholly by trial; the gun may be fired and the path which the projectile follows traced by some suitable experimental method. Second, it may be calculated from the known initial conditions—the muzzle velocity (M.V.) and the quadrant elevation—and the known forces acting on the projectile subsequently. These forces are of two kinds: there is the force of gravity tending to pull the projectile to the earth, and there are the forces of the air, of which the chief is the resistance tending to reduce the speed of the projectile; but lateral forces, tending to deflect the projectile, due to wind and to the spin imposed by the rifling, have also to be taken ultimately into account.[1] Before anti-aircraft guns were used, the method of determining trajectories was the first rather than the second; for the only part of the trajectory which was of importance was that in which the projectile approached the earth again, and this part of the trajectory is easy to determine experimentally. But the second method was employed to some extent for the purpose of determining the effect of minor variations from the conditions in which the experimental trials were made. Now the second method requires a knowledge of the forces acting on the projectile; about the force of gravity everything relevant is known, but the exact nature of the resistance of the air is much more obscure. This resistance depends both on the shape of the shot and on its velocity; there is no method known for determining it from general physical principles; it has to be determined experimentally in conditions closely similar to those to which the calculations are to be applied. But since the only known way of giving a projectile such velocities as it has when it leaves the gun is to fire it from a gun, it is only by determining part or all of the trajectory that the air forces acting on the projectile can be deduced. Accordingly, the only way in which the trajectories can be calculated is this. A certain number of trajectories or parts of trajectories are observed experimentally; from these observations it is calculated what air forces must be supposed to act on the shot in order that it should follow these trajectories; and from the forces estimated in this manner

[1] One other circumstance of minor importance has sometimes to be taken into account. It has to be remembered that the earth is rotating while the projectile is in the air; if the gun is firing north the projectile will fall slightly to the east of the gun; but the deviation due to this cause is so small that it may be neglected for all but the most accurate work at extremely long ranges.

trajectories are calculated arising from initial conditions other than those of the experiments.

It will readily be understood that this method is dangerous if the new trajectories calculated are very different from those of the experiments. But this danger does not arise in naval or ordinary military work because, as has been noted, the only parts of the trajectories which are required to be known are the parts similar to those which can easily be observed. But for an anti-aircraft gun the part of the trajectory which is required is not that near the earth, but rather that at the greatest distance from the earth. And it proved that the experiments and methods of calculation which were adequate for military and naval guns were quite inadequate for the prediction of the part of the trajectory which was of the greatest importance for anti-aircraft work.

It was necessary, therefore, to find some method of determining experimentally the trajectory near the summit when a gun is fired at a high angle and the projectile reaches a height of 20,000 or 30,000 ft. The method adopted was to fire from the gun shells which, when they burst, produce smoke, and to time the fuse of the shells so that they would burst at different parts of the trajectory; at successive shots puffs of smoke were thus produced at different points of the same trajectory. It remained only to find a method of determining the position of these puffs; if that could be done any number of points on the trajectory could be determined, and the whole course of the shell traced in any detail that might be desired.

The position was determined by another application of the principle of the range-finder shown in Fig. 1. Two observers at the ends of a suitable measured base AB each looks through a window for the puff marking the burst of a shell. When they see the burst each marks on his window at A^1 or B^1 the point at which it appears to occur. The line AA^1 or BB^1 joining the observer's eye to the mark on the window gives the direction of the burst, and from the two directions and the length of the base the position of the burst can be calculated. When the burst occurs at a considerable elevation this method is inconvenient because the observers would have to lie on their backs and have the windows arranged horizontally above them. Accordingly, for the vertical window is substituted a horizontal mirror, into which the observer looks in order to see the reflection of the smoke burst. He marks on the horizontal surface the point at which it appears to occur, and from the position of this mark and the known position of his eye the direction of the burst can be deduced as before. The method is very simple and obvious. Its great advantages over all the older methods, employing theodolites and other surveying instruments, is due to the very wide field that is seen by an observer at one time; with a more restricted field the position of the burst would have to be known very accurately beforehand in order that the instrument could be directed so that the burst should be seen at all. The fact that it has been used recently for the first time is due chiefly

to the occurrence of new problems, but also to a careful consideration of those conditions (positions of the mirrors and of the observers' eyes) which make it easy to calculate the position from the observers' marks on the windows or mirrors. The development of the apparatus that has played so large a part in the improvement of anti-aircraft gunnery is due to Sir Horace Darwin, F.R.S., and Captain (later Major) A. V. Hill, F.R.S. To deduce the forces from the path it is useful, but not absolutely essential, to know not only the path followed by the projectile, but the time that it takes to reach the various points on its path. Accordingly a third observer is added, who times the interval between the firing of the gun and the burst, and thus measures the time required for the projectile to reach this point of the trajectory.

By experiments of this nature the part of the trajectory which is of importance for anti-aircraft work can be investigated as easily as the part which is near the earth. But the empirical determination of all the useful parts of all the possible trajectories of an anti-aircraft gun would require so much time and labour that little advance could have been made unless it had proved possible to determine from a small number of trajectories the effect upon the motion of the shell of its speed and shape, of the density of the air and other important factors, with such accuracy that any other trajectory could be calculated from this information without further experiments. Such a result has actually been attained. The older method, which did not permit such calculation, depended on observations made on a small portion only of the trajectory; the newer method permits the whole trajectory to be traced; it is not difficult to realise that a knowledge of the whole trajectory permits the laws of air resistance to be fixed much more definitely than a knowledge of a part of it alone. In practice it is found that the determination of three or four points, suitably chosen on each of three trajectories corresponding to different Q.E.'s but the same M.V. (which must be the highest employed), is sufficient to give the law of air resistance so definitely that any other trajectory of the same projectile can be calculated with all requisite accuracy whatever the Q.E. or M.V.

But even this achievement did not represent all the progress that was necessary if the accuracy of anti-aircraft fire was to be made as great as that of naval or military fire. Even when the forces acting on the projectile are known, the calculation of the trajectory, though not difficult, was exceedingly laborious according to the older methods. Now since the possible positions of the target are much more numerous in anti-aircraft work than when the target is confined to the surface of the earth, the number of trajectories which have to be calculated is correspondingly more numerous, for every new position of the target means a new trajectory, or at least a new point on a trajectory. If no improvement on the older methods of calculation had been possible, the task of calculating all the trajectories required would have required so much time and labour that even if the task could have been completed for a single weapon, any improvement in weapons would have been rendered almost useless by the impossibility of re-calculating all the trajectories in any reasonable space of time.

The problem presented was simply one of pure mathematics, usually regarded as the least practical of all forms of knowledge. Fortunately the war had, for the first time, brought into contact with the problems of gunnery men of academic training to whom the methods of modern mathematics were familiar. A new and simple method of calculating trajectories was devised by Lieut. J. E. Littlewood, R.G.A., F.R.S., and for a time removed one of the greatest obstacles to the development of anti-aircraft gunnery. Later the increasing complexity of the problem required more elaborate methods; but in these developments the work of the pure mathematician was still essential.

One subsidiary consequence of the new method of observing trajectories should be mentioned. It has been noted that the trajectory is affected by the wind, which causes the projectile to "drift" in its direction. When the direction and speed of the wind is known, it is a comparatively simple matter to allow for the forces due to it, for the air forces acting on the projectile are those due to its motion relative to the air. The presence of wind merely means that the motion relative to the air is not the same as its motion relative to the earth, but when the wind is known one motion is easily deduced from the other. But the wind at the heights reached by anti-aircraft projectiles is often entirely different from that on the ground. Hitherto observations on the wind at great heights had been made by sending up pilot balloons and watching their motion. But the "mirror" or "window" range-finder enabled the wind at any height to be determined by observations on the drift of the puff of smoke liberated by the bursting shell. This method is both more rapid and more accurate than that of the pilot balloon and came to be adopted whenever a knowledge of the wind in the upper atmosphere was required. It was required not only for anti-aircraft gunnery, but also for meteorological prediction and for the information of airmen.

VI. "Correctors."

When the momentary position and the velocity of the target and the trajectory of the projectile for any Q.E., M.V. or distribution of wind are known, the problem of determining how the gun should be aimed is formally determinate. If sufficient time were available, the correct direction of the gun could be calculated; or tables or charts could be drawn up giving the results of these calculations for any circumstances which could occur. But of course in practice there would be no time for calculation and the tables would be impossibly cumbrous. Some mechanical method of determining the corrections has to be used.

The simplest possible form of device would be one in which the factors determining the corrections, namely, the height (or range), angle of sight, motion of the target and the wind, were all determined by separate instruments, and some mechanical calculator used to estimate from these the direction in which the gun should be pointed; the calculator might consist of pointers which could be set

to scales of the various factors, and a train of gear wheels and cams might be arranged so that, when they were set, some other pointer indicated the result of the calculation. On the other hand, the ideal arrangement, which would save most time, would be one in which the mere process of determining the factors set the pointers, and in which the calculator did not merely indicate how the gun ought to be directed but actually directed the gun; such an arrangement would be fully automatic. The systems of correctors that are actually adopted lie between these two extremes. It is quite impossible here to give any adequate account of them, but if the reader will understand that in what follows accuracy is often sacrificed to brevity, it may be possible to give him some idea of the principles involved.

In the first place it may be observed that it is most important to make the system automatic in respect of those factors which vary most rapidly, and that automatism is not important for those which vary slowly. Now the wind and the height are the factors which vary least rapidly; accordingly, in all systems the corrections for height and wind are applied by setting pointers to scales, these settings modifying in some manner the apparatus which corrects, more or less automatically, for the remaining factors. The factor which varies most rapidly is the angle of sight[1]; accordingly, correction for angle of sight is invariably automatic. The method of applying the corrections for the other factors always consists (as in the rifle) in turning the sighting tube or telescope to a certain angle relative to the barrel of the gun, so that if the sighting tube is directed at the object the gun is rightly directed. The gun layers keep the sighting tube on the object, while the angle between this tube and the gun is varied according to the corrections for height, motion and wind.

Thus in putting the correct T.E. on the gun, the height is set on a scale in much the same way as the range is set on the sliding back-sight of a rifle. A mechanical link-work, actuated by the variation of the quadrant elevation of the gun, then alters the position of the scale on which the height is set, and with it the angle between the axis of the gun and the sighting telescope or tube, so that this angle is equal to the T.E. Now here a difficulty occurs which is characteristic of the whole problem. A change of Q.E. from (say) 50 deg. to 60 deg. will cause the same motion in the link-work, whatever the height set on the scale of the sight; and yet the change of correct T.E. corresponding to this change of Q.E. will be different according to the height. We cannot simply apply one T.E. for height (or even for range), then apply another for Q.E. (or angle of sight), and be sure that the correct T.E. will be the sum of the two, for the two are interdependent. We must somehow make the change in the angle between the sighting tube and the gun, produced by a given

[1] Or rather direction of sight. For the angle of sight is defined as the angle between the line of sight and the horizontal plane; while the direction of sight may vary by a rotation of the line of sight round a vertical axis, while the angle of sight remains constant. In other words, in order to point the gun directly at the target, we have not only to move the barrel up and down, but also to turn the whole gun round.

motion of the link-work, vary with the height set on the scale. It is clear that this consideration complicates the problem enormously, and as a matter of fact no mechanism devised is, or probably could be, perfect ; all that can be obtained is a T.E. near enough for practical purposes.

The Brocq system of allowing for motion of the target and putting on deflection is very nearly fully automatic in our sense. The height has again to be set on a scale, but once that is done the process of determining the angular velocities causes, by an ingenious electrical arrangement, a pointer on a dial to indicate directly the vertical and lateral deflections that ought to be put on the gun. The layers of the gun keep pointers attached to the gun coincident with those actuated by the electrical arrangement, and while they follow the pointers accurately the deflections will always be those given by the Brocq arrangement. It may be pointed out that the height, as well as the angular velocity, enters into the determination of the deflections of the target, because the time that the shell takes to reach the target depends upon the range and the range varies with the height. And again here the complications introduced by the fact that the influences of the various factors are interdependent, like those of height and angle of sight on the T.E., are still more serious. The "secondary" deflections which have to be added to those automatically imposed in order to obtain the true deflections are sometimes considerable ; if they have to be taken into account, they have simply to be read from charts and imposed by hand.

The wind corrections, which are simply deflections to be added to those due to the motion of the target, are determined from charts and imposed by hand. The charts can be "set" once and for all, since the wind does not change rapidly; but since the correction varies with the range as well as the height, the correction has to be read from the chart for each angle of sight.

Lastly, corrections have to be made for the varying performance of the gun, due to changing muzzle velocity and changing density of the air, which produces a changing air resistance. These are made by setting certain of the scales and mechanical devices before firing begins, but once more their interconnection with the other corrections makes it impossible to obtain perfection.

It is not surprising, therefore, that a very small proportion of the projectiles fired by an anti-aircraft gun reaches the place which it is intended to reach. If one shot in 1,000 does so the results are exceptionally good. Even in dealing with the easier problems of land and sea gunnery, the elaborate range-finders and sighting devices are little more than means for getting the first shots somewhere near the target, so that later shots may be corrected by observation of their results. But such observations are almost impossible in anti-aircraft work. When an anti-aircraft gun is firing rapidly, 20 shots will often be in the air before the first reaches the target ; even if the twenty-first could be corrected instantaneously by the result of the first, the target,

flying at two miles a minute, would often be out of range before that twenty-first shot could reach it. The only way to attain any kind of success is to fire a very large number of shots in a very short space of time distributed more or less evenly over a large region through which it is known that the target must pass. There is then some hope that one of the shots will reach some point within this region at the same time as the target. Such barrage fire, intentionally distributed widely and not aimed at a particular point, has become the standard practice in anti-aircraft gunnery. It makes it desirable that all the guns within a wide area should be controlled as closely as possible by a central station, and that as little as possible should be left to the men at each gun. Such an arrangement is greatly facilitated by the introduction of automatic control, in the sense described, and anti-aircraft gunnery has become increasingly more efficient as it has become more automatic.

VII. Anti-Aircraft Guns and Projectiles.

Before we leave this subject, it will be well to notice very briefly some of the considerations which determine the suitability of a gun and projectile for anti-aircraft purposes. Some of the qualities desired, such as mobility, handiness, durability, and so on, need no special mention, and in any case do not depend upon matters which have just been discussed; but others depend on the form of the trajectory. When the target is moving, it is highly important that the time that the projectile takes to reach it should be as small as possible. In order that this time should be short, it is desirable, if the weight of the projectile is fixed, that its M.V. should be great and its shape such that it experiences little resistance from the air. But if the weight of the projectile is raised the considerations are rather more complicated. An increase in weight means in general a decrease in M.V.; for the charge of propellant which can be used depends on the strength of the gun, and the same charge will usually give the heavier projectile the less M.V. It might seem, therefore, that a light projectile was desirable. But it must be remembered that if two projectiles of the same shape but different weight are fired with the same M.V. the lighter will lose speed more rapidly owing to the resistance of the air; thus a very gentle throw will project a cricket ball to a distance which could not be reached with a paper ball of equal size by the most violent effort. Accordingly, if the heavier projectile is despatched with the same charge of propellant as the lighter, and therefore with a lower M.V., it does not follow that it will take longer to reach a point near the end of the trajectory; though it starts more slowly, it may catch up and overtake the lighter projectile. Now the targets of anti-aircraft guns are usually near the ends of the trajectory, and it has actually been found advisable to use heavier projectiles even at a sacrifice of M.V. Thus the 3-in. Q.F. 20-cwt. anti-aircraft gun was designed to fire a 12½-lb. shell with a M.V. of 2,500 ft. per second. Its range and the speed with which it reached the end of its trajectory were actually increased by substituting a 16-lb. shell without altering the charge, and so reducing the M.V.

to 2,100 ft. per second. The heavier shell has the further advantage that it carries a large charge and more shrapnel ; it has the disadvantage that it puts more strain on the mounting, but it probably decreases the wear of the gun.

Still further advantages could be gained by altering the shape of the projectile so that it offers less resistance to the air. But changes of this nature cannot be made readily because they usually imply a re-design of fuses which leads to many complications. Increase of the weight of the shell and improvement of its form also generally makes the shooting of the gun more consistent and less affected by wind. In fact towards the later stages of the war it was realised that the principle on which the 3-in. 20-cwt. gun had been designed was radically wrong, and that the very high M.V. which was characteristic of it, as compared with the older 13-pdr. 9-cwt. gun (which is nearly of the same calibre), was by no means an unmixed advantage. However, by the time this conclusion was reached, aeroplanes had begun to fly at heights out of range of any possible 3-in. gun ; instead of the gun being re-designed it was replaced by guns of larger calibre.

VIII. Fuse Problems.

The third main problem of anti-aircraft warfare is to burst the projectile at the point of the trajectory which is most suitable for the destruction of the target. All anti-aircraft projectiles fired from guns (and not rifles) are fired by time fuses which are set to explode at a given time after leaving the gun. In all the time fuses of all nations at the outbreak of war the timing arrangement consists of a train of composition, resembling black gunpowder, which is lighted when the shell leaves the gun and explodes the charge when the flame reaches the end of the train ; the time of explosion is set by adjusting the length of the train.

It is obvious that the arrangement is by no means ideal ; no train of gunpowder can be expected always to burn at the same rate ; there are sure to be variations due to slight changes in its composition or in the way it is packed. But the method has been adopted because it works sufficiently well for bursting shrapnel fired from field artillery (the main purpose for which time fuses had been employed before the war) and because it is very difficult to devise any other. The plan which would naturally occur to an amateur would be to use some kind of clock-work to determine the time ; but the difficulties of making a device of that sort will be realised if it is remembered what enormous strain is put on the mechanism when the shell is fired. A shell undergoes as great a jerk when it is started as when it is stopped by a solid obstacle ; the clock mechanism must be such that it will continue to work after it has been dashed on the ground with a speed of something over 2,000 miles an hour. However, the difficulties encountered with the ordinary time fuse were so great that all the belligerents tried to devise some form of mechanical fuse ; the Germans actually used a clock-work fuse for some heavy artillery. A similar fuse had been devised in this country before the end of the war, though not in time

to be of practical service. It is probable, however, that the limitations on the possible output of a device so complicated would have prevented it being used in anti-aircraft work where such large numbers of shells are required.

The irregularities in the burning of the fuse train would not be so serious if a given train would burn at the same rate, however the shell is fired. Unfortunately, the rate of burning depends very greatly on the trajectory. If the fuse is set so that the shell explodes after 5 seconds when it is projected nearly horizontally, it will usually explode after more than 5 seconds if it is projected vertically upwards. The reason for this variation is that the rate at which the train burns depends on the pressure of the air in which it burns; the less the pressure the more slowly the train burns, and if the pressure is sufficiently low the train will not burn at all. The pressure of the air is the sum of two different kinds of pressure: first the general "static" (or barometric) pressure of the air in the neighbourhood which would act on the shell if it were at rest; second the "dynamic" pressure which is due to the motion of the shell through the air and gives rise to the resistance opposing the motion of the shell. It is (in general) greater the greater is the velocity of the shell, and the less the less is the static pressure[1] of the air through which the shell moves. The time which a train of given length takes to burn is greater when the shell is fired vertically upwards than when it is fired horizontally because the rate of burning is decreased both by a decrease of the static pressure and by a decrease of the dynamic pressure which would happen even if the static pressure were constant, since the average velocity of the shell is less, because gravity helps the air resistance to reduce the velocity.

Accordingly, in order to set the fuse so that the shell will burst in the right place, it is not sufficient merely to know the time that it takes to reach that place; there must also be known the rate of burning all along the particular trajectory. As has been noted already, the trajectories used in anti-aircraft work are much more various than those used in naval and military work. Just as assumptions concerning the air-resistance based on the limited trajectories of land and sea work proved inadequate when applied to the more general trajectories of air work, so also assumptions concerning the rate of burning which were satisfactory for the former proved inadequate for the latter. The whole problem had to be investigated afresh.

The most scientific way of attacking the problem would be to determine, first, how the rate of burning varies with the pressure of air and, second, how this pressure varies with the height and velocity of the shell. But again, as in the determination of air-resistance, information concerning the second question is impossible to obtain except from observations on the rate of burning of fuses. Accordingly, though in the later stages of the war research directed to a complete and scientific explanation of the burning of fuses was very successful,

[1] It would be more correct here to say "density" instead of "static pressure." The density is proportional to the static pressure while the temperature is constant, but decreases as the temperature increases.

the fuse scales that have actually been used have been based almost entirely on empirical formulæ designed merely to represent the observed facts without any reference to underlying theory.

A fuse scale states a relation between the "fuse-setting," *i.e.*, the position at which the adjustable part of the fuse is set, and the time that the shell takes to explode after the gun is fired ; the setting of the fuse determines the length of the train that has to burn. The fuse scale does not usually state the time explicitly, but expresses it by the position which the shell will occupy on the trajectory after the time has elapsed ; it gives a relation between the height and angle of sight of the target and the fuse-setting necessary to make the shell explode at the right moment. The experiments which determine the fuse-scale are, of course, those described on p. 3 for determining the trajectory ; the method used for determining the one determines at the same time the other. But just as it is not necessary to observe all possible trajectories and all points along each trajectory in order to determine the path of the projectile, so also a limited number of observations will enable the fuse-scale to be predicted for trajectories which have not been observed. But the purely empirical methods of prediction that have usually been adopted are always apt to break down unexpectedly, and the stricter investigations that have been conducted are of practical as well as of scientific interest. It is worth while to notice a few of the more important results which have been obtained.

It is easy by laboratory experiments to determine the relation between the rate of burning and the air pressure. Such experiments show also that the temperature (which falls notably in the upper regions of the atmosphere and might have been a disturbing factor) is not very important. The static pressure of the atmosphere at all heights is also known, so it would seem that the only matter to be determined is the dynamic pressure. Now the dynamic pressure depends, not only on the velocity of the shell and the density of the air through which it passes, but also on the part of the shell on which it acts. It is the dynamic pressure which produces the air resistance, and if it were the same all over the shell, the same in front as behind, there would be no such resistance. The dynamic pressure is always largest at the nose of the shell and in general decreases fairly regularly towards the base ; at the base the pressure is apt to be negative, that is to say, it is sucking the shell back and not pressing it forward. The dynamic pressure which is probably important for the burning of the fuse is that at the "fuse-hole," where the train of composition communicates with the outside of the shell. It will be apparent from what has been said that this pressure will depend on the position of the fuse-hole on the surface of the shell. Moreover, since the distribution of dynamic pressure (at a given velocity) over the shell depends on the shape of the shell, the rate of burning will depend not only on the construction of the fuse, but also on the shape of the shell into which it is screwed.

This is the first important contribution of detailed research to the problems of fuse burning. It was well known that the same fuse

would burn at different rates on different shells, and that some fuses (*e.g.*, that known as No. 85) were particularly liable to produce "blinds," that is, shells which fail to explode at all, in some guns but not in others. It was suspected at once that the failure was due to a relation between the shape of the fuse and the shape of the shell used with those guns; it was suspected that the dynamic pressure at the fuse hole was exceptionally low, so that the train was apt to cease burning. If this were so a modification of the external shape of fuse or shell should put the matter right; that such a modification would have any effect had scarcely been expected before, and yet it proved entirely successful.

However, explanations of this kind cannot be complete unless the dynamic pressure is actually determined and it is shown that the rate of burning is really determined by the pressure at the fuse-hole. The direct determination is not an easy task. It can be carried out in the laboratory at comparatively small velocities of a few hundred feet per second at the most; but since it is known that the distribution and not only the magnitude of the dynamic pressure varies with the velocity of the shell, results so attained cannot be extended at once to the much higher velocities of projectiles. But from these experiments it is possible to gain some idea of what the dynamic pressure is likely to be at higher velocities, while from observations on the rate of burning of fuses along actual trajectories, compared with the relation between rate of burning and pressure determined in the laboratory, it is possible to calculate what the pressures at the fuse-hole ought to be, if the rate of burning is determined only by the pressure at the fuse-hole. If now it is found that these pressures determined from rates of burning along trajectories agree generally with those predicted from experiments at low velocities, the conclusion may be reasonably made that the rate of burning is determined by pressure at the fuse-hole. The accurate variation of pressure with velocity can be measured once more from rates of burning on a few actual trajectories, and a rational basis obtained for extending the results to other trajectories.

When investigations of this kind were carried out, it was found that the expected results were usually obtained, but not always. Generally, if the muzzle velocity was low it was found that the dynamic pressures calculated from rates of burning agreed well with the results of laboratory experiments, but when the M.V. was high, especially in the 3-in. 20-cwt. gun, the agreement failed. Moreover, the effect of the high M.V. seemed to persist all the way along the trajectory and after the actual velocity of the shell had fallen below the M.V. of a similar shell fired from a gun which gave normal results.

This puzzling effect was finally traced to the spin of the shell. As is well known, projectiles are always set in rapid rotation as they are projected by means of spiral grooves ("rifling") cut in the barrel of the gun; if the gun and the grooves are the same, the speed of rotation will increase with the muzzle velocity, and this spin, being opposed by no appreciable resistance, is preserved throughout the whole trajectory. Now the spin might affect the rate of burning in two ways. First, there may be a direct mechanical effect; the

centrifugal force due to it acts on the composition (or on the "slag" which results from its burning), and may alter its distribution and so the rate of burning. Second, the spin may affect the dynamic pressure. This pressure would be altered if the motion of the projectile became at all inclined to the axis of the projectile; that is to say, if the shell did not travel strictly nose foremost. Now the object of imparting a spin to the projectile is to keep its axis nearly along the direction of motion,[1] and the closeness with which it is so kept will depend on the rapidity of the spin; hence the spin, even if the speed of progression is unaltered, may affect considerably the dynamic pressure at the fuse-hole.

Laboratory experiments in which shells with their fuses were spun very rapidly (up to 30,000 times a minute) showed that there was a very noticeable direct mechanical effect of spin on the rate of burning, and this effect seemed to account for almost all the anomalies without the necessity of introducing an effect due to deviation of the axis of the shell from the line of flight. But the possibility of an effect of the second kind led to a more thorough mathematical investigation of the effect of spin on the actual trajectory of a projectile than had been undertaken before; the results, though not of immediate importance in anti-aircraft work, have undoubtedly to be considered in connection with the more accurate forms of gunnery.

On the practical side, the anomalies due to the effect of spin were largely removed by reducing the rate of twist in the rifling of the 3-in. 20-cwt. gun, which was the chief offender. The spin imparted to the shell was thus reduced without any loss of M.V. The bursting of the fuses became more regular and the fuse scale more in accordance with that for other guns. At the present time it may be said that a stage has been reached at which the fuse scale can be determined directly from laboratory experiments alone without the necessity of firing any trial rounds at all. But at the same time the development of mechanical fuses, mentioned on p. 19, may possibly make all fuse scales obsolete.

The attention paid to this and other problems of anti-aircraft gunnery is justified by the bearing which they have upon other forms of gunnery. The special difficulties of anti-aircraft gunnery have forced artillerists to investigate in a thoroughly scientific manner problems of which they could get solutions, sufficiently accurate under the easier conditions, by mere trial and error. But of course the solutions, when they are found, can be applied to the simpler as well as to the more complex problems; it would hardly be extravagant to maintain that the whole science and practice of artillery has been revolutionised by the development of anti-aircraft gunnery during the war.

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[1] It is not always realised that the spin would not keep the shell travelling nose forward if it were not for the dynamic pressure of the air. If there were no air and spin were imparted, the axis would remain in the original direction of projection and the shell would come to earth base foremost.

CHAPTER II.

ANTI-AIRCRAFT GUNS.

I. First Demands for Anti-Aircraft Guns.

When the war broke out there was no anti-aircraft armament of any description in the British Army, and the only provision for home defence against aircraft consisted of 33 naval guns, viz. :—

1 4-in. gun.
4 3-in. guns.
28 1-pdr. pom-poms.

The pom-poms were of very little value. There was no shrapnel available for them, and the shell provided for them would not burst on aeroplane fabric but fell back to earth as solid projectiles. The aerial defence of the country was handed over to the Admiralty in September, and by October the following additions had been made to anti-aircraft armament :—

9 3-in. guns.
43 6-pdr. guns.
3 3-pdr. guns.

Three 3-in. anti-aircraft guns in addition had been temporarily diverted from ships, and other guns diverted from the naval service were being mounted, viz. :—

1 3-in.
22 6-pdr.
3 3-pdr.
16 1½-pdr.

3-in. high explosive ammunition with night tracer and 3-in. shrapnel had been ordered from Cammell Laird, the Projectile Company, Armstrongs, Vickers, and the Royal Laboratory, and it was hoped that 25,550 rounds of H.E. and 3,300 rounds of shrapnel would be delivered by March, 1915.[1]

By 31 December, 1914, the following guns had been mounted in various districts :—

	3-in.	Hotchkiss. 6-pdr.	Pom-pom. 1-pdr.
London	2	4	6
Thames and Medway	2	29	7 (10 1½-pdrs. to be mounted)
Dover	1	2	1
Waltham Abbey	1	2	2
Purfleet	1	—	2
Woolwich Arsenal	1	2	2
Windsor Castle	—	1	—

[1] Paper by Mr. Churchill on Aerial Defence, Oct., 1914. HIST. REC./R./1960/12.

The London guns protected the centre of London only, and the Home Office had asked for more protection to cover an area six miles from London.[1]

The Zeppelin raid on the night of 31 May, 1915, revealed the weakness of the London defences. Lord Curzon reported that they were "absurdly inadequate."[2] The number of guns was insufficient, and the only effective ones were the nine guns (five 3-in. and four 6-pdr.), which fired time fuse shell. The 3-in. guns, which were sighted to 8,400 yds., were the only ones that could be used against aircraft at a considerable height. The second class of guns consisted of four obsolete 6-pdrs., 15 to 25 years old, mounted at the Foreign Office, Nine Elms, York Road and the Temple. They were sighted to 4,700 yds., but could not be relied upon. The third class of guns consisted of six pom-poms, placed at St. James', the Crown Agents, Gresham Street, Cannon Street, Waterloo and St. Helens, which were provided with percussion fuse shell and were of no use except at a much lower elevation than a Zeppelin attacking London was likely to keep. These guns made no pretence to defend London as a whole—merely a small arbitrary area in the administrative centre of London, and it was extremely doubtful if even for this purpose they would be effective. Their sole value appeared to be that their existence kept a Zeppelin at a certain height in the air, thereby impairing its aim and reducing its power of mischief. Lord Curzon recommended that more 3-in. guns should be provided as soon as possible, and should be mounted in a circle some five or six miles from the centre like the 75 mm. guns in Paris, and that each gun should be supplied with a searchlight.

In the Zeppelin raids of October, 1915, the new mobile anti-aircraft guns (13-pdr. 6-cwt) firing from freshly selected positions well clear of London—at Broxbourne, Loughton, Hatfield, Beacontree Heath, Hainault and Sutton's Farm—came into action for the first time with good effect. The 3-in. (20-cwt.) guns stationed at Clapton, West Ham, Finsbury, Parliament Hill, King's Cross, the Tower, the Green Park, Blackheath, Honor Oak and Barnes, also came into action. Special arrangements were made for the defence of Woolwich Arsenal.

In the meantime, anti-aircraft armament for the British Army in France was being improvised in the same way.

The first record of a request for anti-aircraft guns for service with the army in France that has been found is in a letter from Sir John French of 24 September, 1914. He asked for the provision of one anti-aircraft section of two guns for each division. Instructions were given to the Ordnance Factories (30 September), and trials with the first equipment of 13-pdr. R.H.A. guns converted for use against aircraft were carried out in October, the first section of two guns leaving Woolwich for France in November.[3]

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[1] Paper by Mr. Churchill on Defence of London, 1 Jan., 1915.

[2] Lord Curzon on Defence of London, 10 June, 1915.

[3] Letters quoted in Sir John French's despatch of 31 July, 1915. D.M.R.S. /138, and information given by General Bingham.

The 13-pdr. gun was not really satisfactory owing to its low muzzle velocity, and on 18 February, 1915, Sir John French asked for a more satisfactory weapon, stating that a muzzle velocity of 2,000 ft. per second was required. Increased muzzle velocity became daily more important owing to the height at which hostile aeroplanes flew and the extent of the front to be covered. The supply even of converted 13-pdr. R.H.A. guns was insufficient, and on 31 July, 1915, Sir John French pointed out that he had only 13 sections of 13-pdr. anti-aircraft guns and 2 sections of 2-pdr. anti-aircraft guns (the latter belonging to the Royal Marine Artillery and being manned by them) to supply an army which would shortly consist of 29 divisions.

Two days later, on 2 August, Sir John French asked the Army Council to consider the possibility of converting the 3-pdr. Hotchkiss guns, of which there were 12 in the possession of the Royal Naval Armoured Motor Car Squadrons. He also inquired whether there was any likelihood of a further supply of 2-pdr. naval anti-aircraft guns becoming available. At the same time he asked for 15 sections of 13-pdr. guns, in addition to his previous estimate of one section per division, to protect vulnerable points in the rear of the line which were then unprotected—such as ammunition depots, the headquarters of larger formations, and aerodromes.

> "Although such attacks may be met and the aeroplanes brought into action by our own aircraft, yet the speed of aircraft is so great that it is unlikely that there would be sufficient warning of any attack for our aircraft to intervene successfully before the enemy could drop his bombs. Every point of any importance for some distance behind the enemy's lines is protected by anti-aircraft guns and our aeroplanes suffer much more damage from these than from the enemy's aircraft."[1]

By this time the responsibility for home defence against aircraft attack had been transferred to the War Office. Zeppelin attacks on the North-East coast on 6-7 June and 15-16 June, 1915, followed by raids on Suffolk, Essex and London on August 9th, 12th and 17th, demonstrated the inadequacy of the existing anti-aircraft armament.

The Army Council, therefore, made very large additions to Sir John French's requirement, and on 19 August asked the Ministry to provide 161 18 and 13-pdr. anti-aircraft guns on a 3 or 5 ton motor chassis for use overseas and 200 3-in. Q.F. high angle guns for home defence.

The Army Council aimed at a total of 230 guns with the Expeditionary Force. Towards this number there were :—

With the Expeditionary Force	26
Employed temporarily at home	6
Under conversion (13-pdr.)	22
Available for conversion (13-pdr.)	15
	69

[1] O.B. 478; O.A.2/13G. in D.M.R.S./138.

The number of 13-pdr. H.A. guns available for conversion was limited, and the Army Council proposed (19 August, 1915) that the 18-pdr. Q.F. gun should be modified to take 13-pdr. ammunition, thus securing a higher muzzle velocity. The Ministry thereupon ordered 161 of these 18/13-pdr. guns, 6 guns and 106 mountings from the Ordnance Factories, 100 guns from Vickers, and 55 guns and mountings from Armstrong Whitworth.[1] Deliveries were to begin in December, 1916, and it was hoped that 50 would be ready in February and that the whole number (161) would be completed by June, 1916.[2] These guns were later known as the 13-pdr. 9-cwt. anti-aircraft guns,[3] the original 13-pdr. being a 6-cwt. gun. Satisfactory deliveries of these guns were being obtained in May and June, 1916, in spite of the introduction of a new sighting gear.[4]

Various expedients were adopted to tide over the time before the new guns were ready. The Admiralty lent 36 3-in. anti-aircraft guns in January, 1916,[5] and in February the War Office released 90 18-pdr. guns for use with extemporised anti-aircraft mountings, a mounting simple to manufacture being designed for them,[6] which the Ministry hoped to turn out in about two months at the rate of 8 to 12 mountings per week. On 10 March they were asked to proceed with mountings for the 90 guns which had been released. It was hoped (18 April) that the Coventry Ordnance Works would begin to deliver in mid-June at 6 per week, increasing to 9 per week in July, but by June the mountings were not being produced as quickly as had been anticipated.[7]

On 9 August, 1916, in reply to the War Office request for a certain date of delivery, the Ministry explained that the delay was due to the fact that after the first two mountings had been assembled it was found that the elevating gear worked stiffly owing to muzzle preponderance. To get over this difficulty a balance spring had been fitted to the mounting. The first mounting was about to be tried. If it proved satisfactory, 20 could be promised by the end of September, and afterwards 10 to 12 per week until the 90 were completed.

In September the War Office again complained about the delay in production. The Ministry explained that the delay was due to some additional modifications being found necessary, and by October, 1916, regular deliveries were being made.

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[1] 94/G./699; 94/G./851. (Printed) *Weekly Report*, No. 9, I (25.9.15); No. 12, I (16.10.15).

[2] Minutes by Mr. Ellis, 8 Sept., 1915; Minute by Mr. Layton to the Minister, 22 Nov., 1915. D.M.R.S./138.

[3] Note by Mr. Piggott, 3 Dec., 1915. D.M.R.S./138.

[4] (Printed) *Weekly Report*, No. 40, I (6.5.16); No. 44, I (3.6.16). See also Tables of Issues of Land Service Guns. HIST. REC./H./1200/7.

[5] (Printed) *Weekly Report*, No. 25, I (15.1.16).

[6] 57/Gen. No./5148/A.2/in D.M.R.S./138 A.1.

[7] D.M.R.S./138 A.8.

II. The 3-in. 20-cwt. Gun.

The design for the 3-in. anti-aircraft gun was a very complicated one, and required the same sort of machinery as was being used for 4-in. naval guns, of which the Admiralty had a large number on order. Fifty guns of this type were ordered by the Ministry from Armstrong Whitworth in October, 1915, delivery being expected in April, 1916.[1] Mr. Ellis refrained from ordering the balance of the 200 guns required pending the decision of the Ordnance Board on a new design put forward by Armstrong Whitworth, which had been submitted to the Ordnance Board in September.[2] The new design was simpler than the existing design and would make it possible to supply the guns more rapidly.

The Board's decision was delayed, and on 4 December the Ministry asked if the War Office wished the remaining 150 guns to be ordered to the old pattern in spite of the fact that deliveries would not begin before July, 1916. On 12 December the War Office replied that guns of the old pattern should be ordered unless Armstrong Whitworth's design was ready for adoption.[3] Four days later (16 December) Vickers were asked to make the remaining 150 guns of the simplified design.

III. Additional Orders for Anti-Aircraft Guns placed by the Ministry.

A series of Zeppelin raids in September, October and November, 1915, caused considerable damage, loss of life and delay to munitions production, and at a meeting between representatives of the Ministry and of the General Staff in December it was decided that 126 additional 3-in. anti-aircraft guns beyond the requirements of the War Office as then understood should be ordered for home defence.[4] These guns which were to be of O.F. design, were ordered from Woolwich on 21 December, delivery to begin in April, 1916.[5] On 24 January, 1916, the War Office stated that these additional orders must have been placed under a misapprehension, but on 19 February they expressed their concurrence with the action taken by the Ministry.[6]

By 21 February, 1916, the following guns had been ordered :—

For France—

161 13-pdr. 9-cwt. anti-aircraft guns.

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[1] The contract was dated 14 December. 94/G./784.

[2] D.M.R.S./138. (Printed) *Weekly Report*, No. 7, III (11.9.15) ; No. 9, I (25.9.15).

[3] 79/8217/A.1/in D.M.R.S./138.

[4] D.M.R.S./138.

[5] (Printed) *Weekly Report*, No. 21, I (18.12.15).

[6] D.M.R.S./138.

For Home Defence—

326 3-in. 20-cwt. anti-aircraft guns.[1]
62 13-pdr. 9-cwt. anti-aircraft guns.
73 existing 12-pdrs. to be converted to anti-aircraft guns.
50 existing 6-pdrs. to be converted to anti-aircraft guns.[2]

It was anticipated that the 326 3-in. (20-cwt.) guns would be delivered by the end of the year. By 8 May 218 of them were already in position. Arrangements were also being made for the supply of 75 mm. guns from France for anti-Zeppelin work.

On 6 July, 1916, the War Office asked for 105 additional 3-in. 20-cwt. equipments for the forces overseas.[3] Sixty of these guns were ordered from the Ordnance Factories and 45 from the Coventry Ordnance Works, delivery to begin in January, 1917, and to be complete by May of that year.[4]

A Minute by the Director of Artillery, 27 July, 1916, showed that there were at that date in France :—

10 12-pdr. 12-cwt. guns.
3 3-in. 5-cwt. guns.

Of the 105 additional 3-in. 20-cwt. guns ordered, 10 were for the reserve, so that the establishment in France would be 108 guns, which would be distributed as follows[5] :—

In the Field (24 sections)—		
3-in. 20-cwt. anti-aircraft guns	.. =	48 guns.
On Lines of Communication (30 sections)—		
50 3-in. 20-cwt.	} =	60 guns.
10 12-pdr. 12-cwt.		
Total	..	108 guns.

IV. General Robertson's Scheme, July, 1916.

In order to hasten the equipment of the army in France with 3-in. guns, General Robertson proposed that a portion of the guns of this type already ordered for home defence should be delivered overseas. In a memorandum submitted to the War Committee of the Cabinet on 1 August he recommended that one-third of the deliveries of these guns should be allotted to the British Expeditionary Force.[6] The effect of this proposal would be that overseas forces would benefit greatly during the winter, and would have their full

[1] The Admiralty were to provide 70 more, the requirement for home defence being 396. D.M.R.S./138.
[2] D.M.R.S./138.
[3] 57/3/5111 (A.2), referred to in D.M.R.S./158.
[4] Minute by Col. Symon, 10 July, 1916. D.M.R.S./138.
[5] D.M.R.S./138.
[6] *Ibid.*

equipment minus reserve by the middle of March instead of May. Home defences would lose 20 to 25 per cent. of the number of guns that would be available on the old scheme.

The following table shows the difference between the estimated totals available under the two schemes :—

	Estimates of Deliveries to Overseas.		Estimates of Deliveries to Home.	
	Present.	Proposed.	Present.	Proposed.
31 July, 1916	3	3	95	95
31 Aug., 1916	3	14	127	116
31 Sept., 1916	3	26	163	140
October, 1916	3	38	200	165
November, 1916 ..	3	52	240	191
December, 1916 ..	3	65	281	219
January, 1917 ..	15	78	306	243
February, 1917 ..	39	90	319	268
March, 1917	63	104	385	294
April, 1917	87	108	349	328
May, 1917	108	—	352	352
June, 1917	—	—	364	364
July, 1917	—	—	376	376

The War Committee approved Sir William Robertson's proposal, which was carried into effect.

It will be noticed that the maximum equipment for Home Defence shown in the table above falls short by 20 of the total requirement, the reason being that 20 of the 70 guns that were to be provided by the Admiralty had been diverted to other purposes. The Ministry asked whether it should order 20 more guns to make good this deficiency, but the War Office were not sure whether they had anything to hope for from the Admiralty later on.[1]

The first delivery of 3-in. 20-cwt. guns was in May, 1916, and by 31 August 50 equipments had been delivered to D.D.O.S., 8 having been supplied by the Elswick Ordnance Company and 42 by the Ordnance Factories. By 16 September 74 had been delivered to proof[2] and 144 by the end of the year.[3] There was considerable delay in the provision of the sighting telescopes for this equipment and the Ministry arranged to borrow a certain number from the Admiralty.[4]

V. Withdrawal of 13-pdr. 6-cwt. Guns.

In August, 1916, the Army Council decided that 44 13-pdr. 6-cwt. guns were to be withdrawn from France (some of them being sent to the East) and that they were to be replaced by 13-pdr. 9-cwt. guns on motor lorry mountings.[5] The establishment of 13-pdr. 9-cwt.

[1] Note by Mr. Layton (undated). D.M.R.S./138.

[2] D.M.R.S./138. (Printed) *Weekly Report*, No. 59, Section II. (16.9.16).

[3] *Issues of Land Service Guns.* Hist. Rec./H./1200/7.

[4] D.M.R.S./138 D.

[5] Telegram W.O. to G.H.Q., France, 22 August, in D.M.R.S/138.

guns in France was to be 192 (plus 48 for reserve), while 60 guns of this type (plus 15 reserve) were needed for home,[1] the 6-cwt. guns being gradually eliminated as shown below.

13-PDR. ANTI-AIRCRAFT GUNS FOR HOME DEFENCE.[2]

	13-pdr. 6-cwt.	13-pdr. 9-cwt.
19 September, 1916	22	10
1 October, 1916	26 (4 on loan)	12 (2 on loan)
1 November, 1916	28	22 (2 on loan)
1 December, 1916	30	30
1 January, 1917	15	45
1 February, 1917	—	60

In the meantime there was an urgent demand for guns to arm merchant ships against the German submarine campaign. 190 3-in. 20-cwt. guns were handed over to the Admiralty in January, 1917, and it became necessary to replace them with 13-pdr. 9-cwt. guns. On 16 February, 1917, the gun manufacture department stated that there was a prospect of obtaining 60 13-pdr. 9-cwt. Mk. IV equipments during October, November, and December, 1917, without delaying orders for 18-pdrs. On 21 February the Director of Artillery asked that the provision of these equipments should be arranged for,[3] and they were ordered from the Elswick Ordnance Company.

Special inquiries were made (19 February, 1917) as to the prospects of delivery of both new and re-lined 13-pdr. 9-cwt. guns. The Ministry forwarded the following estimate (24 February) :—

	Guns.	*Carriages.*
February, 1917	15	11
March ,,	24	12
April ,,	27	15
May ,,	27	15
June ,,	17	15
July ,,	10	15
August ,,	3	10
September ,,	—	10
TOTAL	123	103

It was not possible to give an estimate for the delivery of re-lined guns, as that depended upon the receipt of guns for repair, of which the Ministry then had only 16.[4] The Army Council asked (6 March, 1917) that repair of these guns should be given preference over the repair of 18-pdrs.[5]

Deliveries of the new 13-pdr. 9-cwt. guns ordered from the Elswick Ordnance Company were not satisfactory. 35 had been promised for June, but by the middle of July, 1917, only 20 had been delivered.[6] It

[1] Note by Mr. Page, 8 Sept. D.M.R.S./138.

[2] Table given by A.2, 20 Sept., 1916. D.M.R.S./138.

[3] D.M.R.S./138H. D.M.R.S./404 D.

[4] D.M.R.S./404 D.

[5] 57/3/5238 (A.2) in D.M.R.S./138.

[6] (Printed) *Weekly Report*, No. 101, I (21/7/17). Deliveries improved later, and by the end of August exceeded promises. *Ibid.*, No. 108, I (8/9/17).

was decided, therefore (14 November), that the delivery of these guns should be accelerated at the expense of 18-pdr. field guns, 20 additional 13-pdr. 9-cwt. equipments were to be turned out each month from March to September, 1918, inclusive, amounting to 140 additional equipments. These were to be mounted on Peerless lorries which would be provided by the War Office.[1]

VI. Request for a New Design of Anti-Aircraft Gun.

At the beginning of 1917 the need of a more effective anti-aircraft weapon than the 13-pdr. 9-cwt. or the 3-in. 20-cwt. gun became clearly apparent.

The following letter from General Headquarters to the War Office (5 April, 1917) summarises the position and defines the qualities to be embodied in a new weapon[2] :—

> "The 13-pdr. 9-cwt. gun can only be looked upon as a makeshift adopted of necessity at a time of stress with the primary idea of facilitating output. Since its introduction the height and speed attained by aeroplanes have increased to such an extent that the utility of this gun with its low muzzle velocity and light shell has been considerably impaired and is now chiefly confined to preventing aeroplanes flying low over our front line. In addition, the lorry mounting, which was also an improvisation, is not satisfactory.
>
> The 3-in. 20-cwt. gun, though possessed of a considerably higher muzzle velocity, fires the same shell as the 13-pdr. This gun was not originally designed as a mobile gun, and its present mounting limits its use to second line positions and defended areas on the lines of communication. It cannot be employed in the front line owing to the time which is required to move it.
>
> The conditions which should be fulfilled by a new equipment have been carefully considered, but it is not thought possible to lay these down definitely at this stage. The following, however, are the general lines which it is recommended to be considered in the specification for a new design :—
>
> *Calibre and Weight of Shell.* These two questions are closely connected. A considerable increase in shell power is most desirable. To obtain this from the present 3-in. gun does not appear to be possible. An increase in calibre is, therefore, considered inevitable, and the general opinion is in favour of a 4-in. gun.
>
> *Muzzle Velocity.* This should be as high as possible consistent with the necessary limits on the weight of the gun.
>
> The chief consideration with regard to the ballistics of the gun is the necessity of reducing the time of flight of the shell and so the corrections which have to be made for the speed of

[1] *Weekly Review*, 14 Nov., 1917.

[2] O.B./478 in D.M.R.S./138.

the target. The very long time of flight of the present 13-pdr. is one of its most serious disadvantages.

Nature of Ammunition. Fixed ammunition is a necessity. The radius of the head of the shell should be as great as possible.

Mounting. There is a universal demand for some form of caterpillar lorry so that the gun shall not be confined to roads and yet shall be able to move if it comes under heavy hostile fire.

As regards the actual mounting of the gun, seats for the layers which traverse with the gun are a necessary feature.

Sights. The sights of the 3-in. 20-cwt. are considered satisfactory. Good telescopes are essential. Means for laying by Q.E. should also be provided.

By starting with a complete new design in which the whole problem of gun mounting and transport can be considered together, it is hoped that a satisfactory equipment can be produced."

When forwarding this letter (9 April, 1917), the Army Council asked the Ministry to consider the possibility of making the 3-in. 20-cwt. equipments more mobile and to communicate any proposals to the Council as soon as possible.[1] To meet this request, a design for a 3·6-in. gun was prepared (4 July, 1917), and it was decided that one trial equipment with two guns should be manufactured at the expense of two 60-pdrs.[2] This 3·6-in. gun and a 3·3-in. gun which was also being considered had small charges, and the muzzle velocity of 2,400 ft. per second was obtained by increasing the length of the gun.[3] In the meantime, as these were likely to take some months to complete and the need for a gun more powerful than the 3-in. 20-cwt. was urgent, the adoption of the 4-in. Mark V on a Mark III high angle mounting, which was already being manufactured for the Navy, was recommended. It threw a shell weighing 31 lb. and had a muzzle velocity of 2,350 ft. per second.[4]

The War Office applied for 100 of these guns to the Admiralty, but they were unable to provide them. Thereupon (9 January, 1918) the Chief Superintendent of Ordnance Factories undertook to produce 50, and to deliver 3 a month, beginning in April, 1918, gradually increasing to 6 a month ; 5 were actually delivered in April, and by 10 August, 1918, 11 guns were in action, 2 in France and 9 at home.[5] About 15 December, 1917, the following proposals were made for rendering the 3-in. 20-cwt. more powerful and mobile :—

(1) That the 3-in. 20-cwt. on its own cradle and carriage should be mounted on a caterpillar truck to be drawn by a caterpillar tractor.

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[1] 121/Stores/6904 A.1 in D.M.R.S./138.

[2] *Weekly Review*, 4.7.17. (Printed) *Weekly Report*, No. 106, XII (25.8.17).

[3] 15 Dec., 1917. D.M.R.S./138 K.

[4] The naval service type had a muzzle velocity of 2,600 ft. per second.

[5] *Weekly Review* (1.12.17, 9.1.18). D.M.R.S./138*b*.

(2) That the 3-in. 20-cwt. on its own cradle and carriage should be mounted on a suitable motor lorry chassis and should fire a 16-lb. shell about 2,000 ft. per second. The object of using the 16-lb. shell was to give an improved trajectory and prolong the life of the gun.[1]

The Army Council also accepted (4 February, 1918) the proposal put forward by the Ministry to use the 13-pdr. 9-cwt. gun in a special cradle on the 3-in. 20-cwt. mounting on a 3-ton lorry.[2]

VII. Unsatisfactory Deliveries of 3-in. 20-cwt. Guns.

By the end of 1916, 161 3-in. 20-cwt. guns had been issued to service, but deliveries of these guns were far from satisfactory during 1917. In August only 2 complete equipments were received, although 11 had been promised, and by the end of September only 220 guns had been delivered to Woolwich for proof, 24 guns in excess of mountings, 17 of these surplus being without breech mechanism.[3] Twenty-four more of these guns were still required to complete the London barrage, and 16 were wanted to reinforce the Eastern section. The Admiralty had promised 18 guns by the end of October, but the suggestion that the remaining 22 could be obtained from the Grand Fleet fell through, and owing to the increased activity of submarines a number of 3-in. A.A. guns had to be diverted to merchant ships.[4] In consequence the War Office decided that the deliveries of these guns must be accelerated at the expense of 60-pdrs., and an order was given (14 November) for 90 3-in. 20-cwt. guns to be produced at the expense of 60 60-pdr. guns, gun mountings and carriages.[5]

In October, 1917, it was found that defence by barrage fire could not be continued indefinitely owing to the great wear and tear of the guns, which required re-lining after 1,200 to 1,500 rounds, and the heavy expenditure of ammunition. Already some guns were worn out and had had to be replaced. If raids continued on the same scale, in a few months there would be no defence. Another disadvantage of the barrage was the danger from unexploded shell. On the other hand, hostile aeroplanes were turned back or compelled to operate at a high altitude as a result of the barrage. The difficulty was met by the use of reduced charges for barrage work. Moreover, when the submarine situation improved a certain number of guns were diverted from merchant ships to the London defences.[6]

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[1] D.M.R.S./138 K. 15.12.17.

[2] 121/Stores/8019 (A.2). D.M.R.S./138 K.

[3] *Weekly Review*, 26 Sept., 30 Sept., 1917.

[4] Mr. Churchill's papers, 33/12.

[5] *Weekly Review*, 14.11.17.

[6] Mr. Churchill's papers, 33/16.

VIII. The 1918 Programme.

On 21 February, 1918, a statement of the new requirements of 13-pdr. 9-cwt. and 3-in. 20-cwt. for home and all theatres during 1918 was prepared[1] as follows :—

STATEMENT OF ANTI-AIRCRAFT REQUIREMENTS FOR 1918.

	13-pdr. 9-cwt.			*3-in. 20-cwt.*	
	Guns.	*Mountings.*		*Guns.*	*Mountings.*
New equipments required for arming new units in :—					
France and Italy	40	40	..	90	90
Home Forces	6	6	..	62	62
Minor theatres	18	18	..	—	—
Total	64	64	..	152	152
New equipments required for re-arming units equipped with 13-pdr. 9-cwt.	38	38	..	—	—
Ditto. 12-pdr. and 3-in. 5-cwt.	—	—	..	46	46
To replace 12-pdr. 3-in. 5-cwt.	—	—	..	11	11
Total	38	38	..	57	57
New and repaired equipments required for maintenance in all theatres, and to create an adequate reserve	315	32	..	250	20
Grand Total ..	417	134	..	459	229

IX. Replacement of the 13-pdr. 9-cwt. by the 3-in. 20-cwt. Gun.

The 3-in. 20-cwt. gun firing the 16-lb. shell was found, after trial, to be a better all-round weapon than the improved 13-pdr. 9-cwt.

It was decided, therefore, to adopt it, and on 2 February, 1918, the War Office urged the Ministry to make special efforts to expedite production of 100 guns—50 (*i.e.*, 25 sections) to be mounted on motor lorry chassis and 50 on caterpillar trucks.[2] The order for the latter was cancelled in August owing to manufacturing difficulties.[3] On the completion of the 85 carriages and 140 guns already ordered, manufacture of the 13-pdr. 9-cwt. gun was to cease, except to replace irreparable wastage. The conversion of all 13-pdr. 9-cwt. guns to take the 16-lb. shell, and to be mounted on 3-in. 20-cwt. mountings and provided with Peerless motor lorries, was to be carried out as quickly as possible.[4]

On 30 July the War Office asked for a supply of 3-in. 20-cwt. equipments, mounted on motor lorries, with an effective height of 20,000 ft. at 3,000 yards horizontal range, to move quickly across

[1] D.M.R.S./138 K.
[2] O.C. Minutes, 25402 in D.M.R.S./138 K.
[3] 22 August, D.M.R.S./138 K.
[4] 121/Stores/8019 (A.2), 15 March, D.M.R.S./138 K, 24.2.18.

country with forward sections. These were to replace the 13-pdr. 9-cwt. guns in France, and were to fire at lower elevations than in the case of the existing 13-pdr. mounting.[1]

X. Provision of Spare Guns.

On 15 March, 1918, the Army Council suggested that, on account of the short life of the 3-in. 20-cwt. gun, three guns should be provided to each mounting.[2] The Ministry protested (10 April) that this surplus was in excess of actual needs, and suggested that, once establishment was complete and a large enough reserve had been formed to provide for the absence of guns from the line during repair, guns need be supplied in excess of mountings only to the extent to which casualties to guns exceeded those to carriages.

The number of surplus guns to be provided depended on :—

(*a*) The ammunition available.
(*b*) The life, in rounds, of the gun.
(*c*) The number of firing points.
(*d*) The time taken in repair.

The life of a gun was then estimated at about 3,000 rounds, and the ammunition requirement was about 20,000 rounds per week, which was equivalent to the wearing out of 7 guns a week, or 30 a month. The 3-in. 20-cwt. took about four months to repair and return, and there was no difficulty in repairing 30 guns a month. Moreover, additional 3-in. 20-cwt. guns could only be produced at the expense of 18-pdr. field guns, and as more highly skilled labour was required for the former the loss would be greater than the gain.

The Army Council maintained that a surplus of 460 guns would be required even at the expense of 18-pdrs. (13 April, 29 May, 1918), since barrage charges, though prolonging the life of the gun, were a temporary expedient which detracted from efficiency and had only been resorted to in order to meet the shortage of guns. They urged that the use of this powerful anti-aircraft equipment was being seriously hampered by want of gun-bodies.[3] On 12 June, however, the Army Council reduced their demands, accepting the Ministry's suggestion to provide a surplus of 143 guns only, their reason being that the Commander-in-Chief, France, had asked for an increased proportion of barrage ammunition and the early introduction of the 16-lb. shell, which the Army Council had been informed might be expected to prolong the life of the gun.[4] Experience showed, however, that the life of this type of gun was only about 1,500 rounds, and on 30 July, 1918, the Army Council asked

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[1] War Office Letter, 57/3/5500 (A.2).

[2] Conference at W.O., 21 Feb., 1918. W.O. Letter 121/Stores/8019 in D.M.R.S./138 K.

[3] 121/Stores/8019 in D.M.R.S./138 K.

[4] D.M.R.S./138 K.

that every effort should be made to deliver by the spring of 1919 the surplus of 460 guns originally asked for.[1]

By October the total deliveries on the requirements for 1918 amounted to 486 guns and 384 carriages, which showed an excess on the anticipated deliveries.

XI. New Types of Guns.

In July, 1918, the Army Council again asked for a more powerful anti-aircraft gun, and suggested the adoption of a new 3·6-in. type equipment on caterpillar trucks for overseas, and on fixed mountings for use at home, to fire a shell of about 25 lb. weight, and to have an effective height of 25,000 ft. at 4,000 yards horizontal range. The mounting was to allow of a large radius of action and an elevation from point blank to 85 deg. This type was required to engage enemy scouting machines in all areas, and was to amount to 25 per cent. of anti-aircraft guns for all theatres. At the same time, the Army Council emphasised the importance of introducing a satisfactory long burning, or preferably a mechanical fuse, for anti-aircraft guns.[2] The 3·6-in. gun had to be manufactured on machinery then making 60-pdrs. or 6-in., and as it had a very complicated mounting it could only be turned out by the Royal Gun Factory. A 3·3-in. gun was also being experimented with, and on 6 August the Minister urged that supply of the new type should be hastened. The Army Council preferred that the 3·6-in. gun should be manufactured " rather than await the construction and testing of further designs which may or may not prove superior, but which will certainly delay re-armament."[3] In September the design was approved and an order placed with Woolwich for 80-100 on caterpillar mountings to be supplied during 1919.

In November, 1918, the War Office cancelled their order for 100 equipments, substituting one for 4 trial mountings, 2 on caterpillar trucks and 2 on fixed mountings.[4]

The War Office demand for anti-aircraft guns for the year September, 1918, to October, 1919, was a very large one—

Type.	*Guns.*	*Mountings.*
3·6 in.	672 ..	340 (120 mountings on caterpillar trucks, 220 fixed mountings)
3-in. 20-cwt. ..	1,243 ..	342
13-pdr. 9-cwt. ..	50 ..	—[5]

and the Ministry was unable to promise more than 80 to 100 3·6-in.

[1] *Weekly Review*, July 31.

[2] W.O. Letter (30 July), 57/3/5500 (A.2), D.M.R.S./138 K.

[3] 2 Sept., 57/3/5500, D.M.R.S./138 K.

[4] D.M.R.S./138 K.

[5] W.O. Letter 57/3/5500 (A.2), D.M.R.S. 138 K.

and 1,000 3-in. 20-cwt. (guns new and repaired), while the 13-pdr. 9-cwt. guns could only be produced at the expense of the new type (Mark IV) of 18-pdrs.[1]

XII. Guns for Australia.

On 2 May, 1918, the Governor-General of Australia telegraphed to the Secretary of State for the Colonies, stating that it was desirable to have anti-aircraft guns in Australia and asking for 40 guns on movable mountings of the most satisfactory pattern, with ammunition. If the guns were unobtainable, drawings were required for mounting the 18-pdr. H.A., also platform travelling H.A. mountings of the latest mark.[2]

The Governor-General was informed that no anti-aircraft equipment could be spared that year and only a limited amount of 18-pdr. ammunition, for which he was asked (22 May) to state his requirement.[3] This was as follows (5 June)[4] :—

13,500 18-pdr. H.E. with 14,000 fuses, percussion 44/80
and 14,000 fuses, percussion 80/44
7,000 18-pdr. Shrapnel with 7,300 fuses, time 180

It was decided (24 June) that this could be supplied as required, and arrangements were made for forwarding drawings of guns and ammunition.[5]

XIII. Improvements in Anti-Aircraft Armament.

The following extract from a report of General Bingham's summarises the improvements in the efficiency of anti-aircraft weapons during the war.[6]

> " Owing to the shortage of other guns for some time, it was necessary to place existing types of guns on improvised high-angle mountings. The maximum height to which these guns could fire was just over 10,000 ft. We now have special guns on mobile mountings that can effectively fire at aeroplanes flying at a height of more than five miles.
>
> " Instruments which determine in a few seconds the height at which the aircraft are flying have been produced together

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[1] 14 October. D.M.R.S./138 K.
[2] *Weekly Review* (8.5.18).
[3] 57/20/704 (A.2b) in D.M.R.S./138 B.
[4] Colonial Office, 27376/1918 in D.M.R.S./138 B.
[5] D.M.R.S./138 B.
Report to Mr. Kellaway, Feb., 1919.

with complicated apparatus which make accurate allowance for the travel of the aeroplane during the long interval between the firing of the gun and the burst of the shell. Incidentally, anti-aircraft shell are now fired every day in order to ascertain the speed and direction of the wind at high altitudes, as it has been found that such reports are invaluable assistance in preparing the weather forecast, and in providing aeroplane pilots with accurate knowledge of the wind prevailing up above."

An Anti-Aircraft Equipment Committee, formed by General Bingham on 23 March, 1917, did very useful work in connection with anti-aircraft gunnery problems.[1]

[1] Anti-Aircraft Equipment Committee. HIST. REC./R./1980/3.

CHAPTER III.

AMMUNITION FOR ANTI-AIRCRAFT GUNS.

I. Types of Anti-Aircraft Ammunition.

The bulk of the ammunition provided for anti-aircraft guns was either 13-pdr. or 3-in., though a variety of miscellaneous shell had to be supplied for the 1-pdr., 6-pdr., 10-pdr. and 12-pdr. guns until they were replaced by more satisfactory weapons. The 13-pdr. shell could be used in both types of 13-pdr. equipment— the 6-cwt. and the 9-cwt. —as well as with both types of 3-in. guns—the 5-cwt. and the 20-cwt.

When 13-pdr. shell was used with the 3-in. gun a reduced charge of cordite (2 lb. 5 oz. M.D. size 11) was recommended by the Ordnance Committee.[1] A special size of cordite was also required for use with the 3-in. shell in the 3-in. 20-cwt. gun. The charge was calculated from a specially large size M.D. 11 cordite manufactured for the Admiralty. A similar charge of the ordinary M.D. cordite gave too high a pressure and a lower charge reduced the muzzle velocity of the gun by 70 ft. per second, which was a serious matter in the case of an anti-aircraft gun. The Director of Artillery was very anxious that a sufficient supply of the large size cordite should be provided as soon as possible. A small amount had been borrowed from the Admiralty, but this would have to be repaid. On 21 June, 1916, therefore, Sir Frederick Nathan was asked to provide enough of this special cordite for 250,000 rounds of 3-in. 20-cwt ammunition at the rate of about 10,000 per week during the next six or seven months—*i.e.*, about 330 tons at the rate of about 13 tons a week. Sir Frederick Nathan hoped that the supplies would be available from the middle of July, 1916.[2] Owing to a shortage of this special cordite, supply of this ammunition was temporarily suspended in June, 1916.

There was some doubt whether the H.E. and shrapnel shell approved for the 3-in. (20 cwt.) gun would be suitable for the 3-in. (5-cwt.) gun of Armstrong's design, and whether the same charge and the same cartridge cases would serve. On 22 March, 1916, the Ordnance Committee decided that the universal 3-in. shrapnel and H.E. shell could be used with the 5-cwt. gun and that the charge should be 8 oz. M.D. 4¼ 72/16 oz. size 8.[3]

Shrapnel and H.E. shell for anti-aircraft guns were at first asked for in almost equal proportions, but the proportion of H.E. used for home defence gradually increased. On 11 March, 1916, the Director of Artillery stated that the proportion for all anti-aircraft guns (above

[1] 16 May, 1916.
[2] D.M.R.S./138.
[3] Ordnance Committee Minutes 2336. D.M.R.S./W.O.R./315.

6-pdr.) for home defence should be 75 per cent. H.E. and 25 per cent. shrapnel,[1] and the same proportion was demanded for overseas guns on 2 September, while later part of the shrapnel supply for home defence was replaced by incendiary shell,[2] the proportions asked for by the Army Council being 10 per cent. shrapnel, 50 per cent. high explosive and 40 per cent. incendiary.[3]

For home service the 3-in. shell was supplied with a night-tracer, but for use abroad the shell was fitted with a plug instead of a night-tracer.[4] In October, 1917, as there was a shortage of night-tracers for home defence, it was proposed to ask the Boards of Management to make 10,000 per week 18-pdr. night-tracer at the expense of 18-pdr. smoke shell, and in addition a small quantity of 3-in. 20-cwt. night-tracer shell was asked for.[5] A few days later (10 October) it was decided, owing to the wear on the gun caused by the use of full charges, to provide an equal proportion of reduced charges without night-tracers. This would quadruple the life of a gun. A night-tracer was still to be used with a full charge in the 3-in. 20-cwt. The difficulty of supply became so acute that the War Office, while urging forward output, temporarily allowed ammunition to be accepted without night-tracers (24 October). The following month (7 November), the Chief Superintendent of Ordnance Factories represented to the War Office that there was considerable danger to life in the preparation of night-tracers, and asked that their use might be suspended until the danger had been eliminated. On 1 December it was decided that in future night-tracers should not be provided with anti-aircraft ammunition for home defence.[6]

Owing to the difficulty of observing bursts of anti-aircraft ammunition filled with amatol, filling with T.N.T. was tried[7] (November, 1917).

II. Fuses for Anti-Aircraft Ammunition.

The supply of fuses for anti-aircraft ammunition will be considered in detail elsewhere. Here it is sufficient to notice that the problem of finding a really satisfactory fuse was a difficult one, owing to the fact that the rates of burning of powder-filled time fuses varied with variations of altitude. The clockwork fuse No. 200, which was just coming into supply at the date of the Armistice, promised a solution of this problem. It could be regulated to carry for 60 or 90 seconds without bursting, and functioned quite accurately at the time set.

[1] Ordnance Committee Minutes 2190 ; 2 September, 75/12/9383 in D.M.R.S. /138.

[2] See below, pp.

[3] 75/12/9383 (A.1) in D.M.R.S./356.

[4] D.M.R.S./138.

[5] (Printed) *Weekly Report*, No. 112, Section II. (6.10.17).

[6] *Weekly Review*, 6 October—1 December, 1917.

[7] A.2b/1917/1819 in D.M.R.S./138 B.

III. Review of Demands for Anti-Aircraft Ammunition.

From the nature of the case the demands for anti-aircraft ammunition, whether for home defence or for service abroad, were very irregular and usually took the form of a demand for a certain number of shells to equip each gun rather than for a definite weekly or monthly supply. This, together with the fact that the demands were very small as compared with those for ordinary artillery ammunition, complicated the question of supply, and the Ministry found it difficult to meet this series of fluctuating demands.

3-in. Ammunition.

As has been seen, 3-in. shell for home defence had been ordered by the Admiralty in 1914. On 19 August, 1915, the War Office asked for 60,000 rounds of H.E. and 40,000 rounds of shrapnel for the 200 3-in. guns that were being ordered for home defence,[1] and deliveries of this type of ammunition began in May, 1916.

During 1915 the bulk of the anti-aircraft guns overseas were supplied with 13-pdr. shell, comparatively small amounts of 15-pdr. shell, which was used with the 12-pdr. gun, being also provided.[2] On 28 July, 1916, the Director of Artillery asked for 43,800 rounds of 3-in. and 3,000 rounds of 12-pdr. per month, the proportion being 50 per cent. H.E. and 50 per cent. shrapnel. The question whether incendiary shell should be provided was being referred to G.H.Q., France.[3] On 28 August 12,000 complete rounds of 3-in. shrapnel were demanded for the 12 3-in. guns that were being handed over to the Expeditionary Force by the Navy.[4] In view of a large prospective increase in the demand for 3-in. shell for overseas it was proposed that a special design of shell should be made for the guns overseas, instead of using the 3-in. universal shell with a plug instead of a tracer, and that it should be fitted with a fuse burning 30 seconds, *i.e.*, a fuse of the 87 type.[5]

18-pdr. Anti-Aircraft Shell.

On 10 March, 1915, ammunition was ordered to supply the 90 field guns which were to be fitted with anti-aircraft mountings, 500 rounds per gun (H.E. 75 per cent., S. 25 per cent.) with night-tracers, and T. and P. fuses, for the first equipment and 100 rounds per

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[1] 121/Stores/1537 (A.2) in D.M.R.S./138.

[2] Large stocks of 15-pdr. shell were in existence in June, 1917, and manufacture was discontinued. D.C.M.D./G/0124; D.M.R.S./138 B.

[3] D.M.R.S./138.

[4] D.M.R.S./W.O.R./84.

[5] D.M.R.S./138, D.G.M.D./S./545.

gun every six months after. Assuming the deliveries of guns to begin in June, ammunition would be required as follows :—

	H.E.		S.
June	4,500	..	1,500
July	13,500	..	4,500
August	13,500	..	4,500
September	2,250	..	750
	33,750	..	11,250

As there was likely to be some delay in the manufacture of this shell, the War Office consented (27 March) to accept ordinary service ammunition as a temporary measure, but urged the importance of the early provision of the correct shell, especially the H.E. type.[1]

A further requirement for 60,000 of these shells (shrapnel and H.E. in equal proportion) was received in August, delivery to be at the rate of 2,000 H.E. and 2,000 shrapnel per week.[2] It was proposed to utilise the existing standard 18-pdr. shrapnel shell by fitting them with base plates containing night-tracer holders. On 12 December the War Office asked that the existing service equipment ammunition should be replaced with night-tracer shells to the extent of 6,000 shrapnel and 15,000 H.E.

On 17 January, 1917, as the 18-pdr. anti-aircraft guns were likely to remain in use for some considerable time, the War Office asked that provision should be made for 18-pdr. incendiary A.Z. shells, 200 rounds per gun, up to 40 per cent. of the total requirement, as follows[3] :—

First Equipment.	*Upkeep every 6 months.*
H.E. 22,500	4,500
S. 4,500	900
A.Z. 18,000	3,600

By 19 April, 1918, the stock of 18-pdr. anti-aircraft shell for home defence amounted to 130,000. This appeared to be sufficient to meet any requirements that were likely to arise, and it was decided that manufacture of this type should cease, but arrangements were made to begin production again within six weeks of receiving a demand.[4]

13-PDR. 9-CWT. H.E. AMMUNITION.

This ammunition was required at the rate of 30,000 per week, from November, 1916, onwards.

By the beginning of 1917 about half the quantity required was being produced weekly, but it was hoped that during March it could be delivered at the rate of 20,000 per week, working up to 30,000 in April. On 21 March, however, the Director of Artillery stated that a maximum of 25,000 rounds a week would be sufficient, of which 6,250

[1] D.M.R.S./138 A.1 W.O. 79/8337/A.1.

[2] (Printed) *Weekly Report*, No. 54, Section III. (12.8.16) ; No. 55, Section III (19.8.16).

[3] D.M.R.S./138 A.8. W.O. 75/12/9383 (A.1).

[4] 57/Gen. No./6591 (A.2 c), D.M.R.S./138P.

should be shrapnel and 18,750 high explosive.[1] Later in the year, however, the demand again rose, and on 26 January, 1918, the War Office asked that the weekly supply of this shell for overseas should be increased from 30,000 to 40,000 rounds, half of which should be high explosive and half shrapnel. As shrapnel steel was scarce, the Ministry stated that the proportion of shrapnel could not be more than 25 per cent., unless it were supplied at the expense of 18-pdr.[2]

In April it was decided that by special distribution and care it would be possible to provide 10,000 rounds of shrapnel per week for twelve weeks.[3]

75 MM. SHELL.

In consequence of frequent daylight air raids the War Office asked the French on 14 July, 1917, for a supply of 3,000 H.E. shell for use in the 75 mm. gun. They were informed by the French that H.E. was not being used for the defence of Paris. The order, therefore, was changed to shrapnel, and at the same time the War Office requested that a supply of 500 shrapnel and 500 incendiary shell, previously ordered from the French, should be hastened. By the end of the month (July) this ammunition had been delivered.[4]

On 29 September, during the week of moonlight aeroplane raids, an urgent demand for further supplies was met by a fresh application to France for

6,440 rounds incendiary,
2,260 rounds shrapnel.[5]

In the following spring (24 April, 1918) the War Office asked for 8,000 rounds H.E. and 2,000 A.Z. They considered that the existing stocks of shrapnel—21,000 rounds—would be sufficient for the time being.[6]

INTRODUCTION OF THE 16-LB. SHELL.

In September, 1917, the use of barrage fire in the defence of London became general, and a reduced charge of propellant was introduced with the object of reducing the wear of the gun, which with the full charge and the 12½-lb. shell was serious.[7] In December, 1917, trials were made with a 16-lb. shell with a 6-c.r.h. head in the 13-pdr. and 3-in. 20-cwt. guns. These trials proved satisfactory, and the shell gave an improved trajectory and increased the power of the gun. Early in 1918 (5 February) there was an urgent demand for both shrapnel and H.E. of this type for the 3-in. 20-cwt., as the

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[1] 121/Stores/6357 in D.M.R.S./138.
[2] *Weekly Review*, 30.1.18.
[3] *Ibid.*, 10.4.18.
[4] *Ibid.*, 14.7.17.
[5] *Ibid.*, 29.9.17.
[6] *Ibid.*, 24.4.18.
[7] Ordnance Committee Meeting at Armament Buildings, 6 June, 1918. 3284.

shell could be fired from this gun however mounted.[1] The existing requirement for shrapnel had been so small (3,000 per week) that, as there was a stock of 150,000 in hand, manufacture had ceased and the steel had been diverted, but the supply of H.E. presented no difficulty.[2] Supplies of 16-lb. shells for the 13-pdr. 9-cwt. gun would have to be concurrent with deliveries of the 3-in. 20-cwt. mountings which were being made with special cradle to take the 13-pdr. 9-cwt. gun. On 15 March the War Office wrote pressing for the early delivery of 16-lb. ammunition, which would materially improve the efficiency of anti-aircraft defences at home and abroad,[3] and on 13 April it was decided that, as soon as deliveries of the 16-lb. shell admitted, the total output of H.E. for the 3-in. and 13-pdr. guns should be made up with this shell and full charges, and (7 June) that the use of barrage ammunition with 12½-lb. shell should be discontinued. It was thought that the wear of the gun with a 16-lb. shell and a full charge would be about the same as with the 12½-lb. shell and a barrage charge. No barrage charges were to be used with the 16-lb. shell,[4] as the Air Board thought that with improved training the chance of obtaining direct hits had improved. Further, the proposed introduction of tin foil to prevent the coppering of the gun and of graphite grease to reduce wear would increase the life of the gun.[5] By 27 April supplies of 16-lb. H.E. shell were being bonded and the output worked up, and it was thought that allowing for inspection 2,000 to 3,000 would be delivered in May. The shrapnel being more complicated was to follow in a few weeks' time. In July it was discovered that the life of the 3-in. 20-cwt. gun with this shell was only 2,000 rounds, and the Army Council were asked if they would reconsider the general adoption of the 16-lb. and revert to the barrage charge with the 12½-lb. shell.[6] They decided, however, to let the requirements stand as they were.[7]

4-IN. SHELL.

4-in. (Mark IV) shell was asked for in small quantities in October, 1917, and in the following month 100,000 rounds of the Mark V type were ordered for the 100 guns of this calibre.

THE 1918 AMMUNITION PROGRAMME.

On 24 April, 1918, a greatly increased demand for all kinds of anti-aircraft ammunition for home and abroad was received by the

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[1] 15 December, 1917. D.M.R.S./138 B.

[2] D.M.R.S./138 P.

[3] 121/Stores/8019 (A.2) in D.M.R.S./138 K.

[4] Ordnance Committee Meeting, Armament Buildings, 6 June, 1918. 3284.

[5] *Ibid.*

[6] 12 July, 1918, D.M.R.S./138 P. The estimated life of the 3-in. 20-cwt. gun was as follows :—

With 12½ lb.-shell, full charge	.. .. ..	1,500 rounds
reduced charge	.. ..	6,000 ,,
16-lb. shell, full charge	.. .. ..	2,000 ,,

[7] W.O. 121/Stores/8019 (A.2 B). D.M.R.S./138 P.

Ministry. The following table shows the old and the new requirements per month and the monthly increase :—

	Per Month. Old.	*Per Month. New.*	*Monthly Increase.*
3-in. 20-cwt. H.E.	32,000	52,778	
S.	6,000	12,411	
	38,000	65,189	27,189
13-pdr. 9-cwt. H.E.	92,000	154,428	
S.	76,000	51,778	
	168,000	206,206	38,205
4-in. Mk. V H.E.	5,556	15,556	
S.	—	4,444	
	5,556	20,000	14,444

Of the 3-in. ammunition, 20,000 rounds 12½-lb. H.E. were being handed over to the Admiralty instead of the 90,000 originally offered. This reduction was due to the requirements of the War Office for 13-pdr. guns.[1]

On 29 May, 1918, the programme for home defence issued on 1 November, 1917, was considerably reduced, as the expenditure from September, 1917, to May, 1918, had been small.

	Total Quantity.	*Weekly.*
18-pdr.	1,000	nil
3-in. 20-cwt.	15,000	500
13-pdr. 9-cwt.	1,000	nil

At the same time, permission was given for the output of 18-pdr. and 13-pdr. 9-cwt. to be entirely suspended if it would assist in the production of the 100,000 18-pdr. incendiary for France, asked for in May, 1918.[2]

The revised requirement for home defence and overseas was issued on 30 October. It was based on the assumption that in the event of heavy expenditure supply could be increased within 21 days of receipt of a further request.

Nature.	*Home.*	*France.*	*Total.*
4-in. Mk. V H.E.	1,500	500	2,000
Do. Shrapnel	nil	250	250
3-in. 20-cwt. H.E. (full charge 16-lb. shell)	2,000	3,000	5,000
Do. H.E. reduced charge	—	—	—
Shrapnel (full charge) (16-lb. shell)	—	1,000	1,000
Do. reduced	1,000	—	1,000
13-pdr. 9-cwt. H.E.	—	20,000	20,000
Do. Shrapnel	—	15,000	15,000

In addition, 100 to 120,000 rounds of 3·6-in. ammunition were likely to be required (9 October).[3]

[1] *Weekly Review*, 24.4.18.

[2] W.O. 57/Gen. No./6591 (A.2 C). D.M.R.S./138 P.

[3] *Weekly Review*, 30 Oct., 1918.

IV. Incendiary, Smoke, and Star Shell for Anti-Aircraft Guns.

INCENDIARY SHELL.

On 12 June, 1916, the Ministry reported that an incendiary shell filled with thermit and ophorite for the 3-in. 20-cwt. anti-aircraft gun had been tried by the Ordnance Committee with promising results.[1] The shell was designed to attack Zeppelins. It was burst by a time fuse, and after bursting ejected molten thermit slowly during the remainder of its flight for a distance of at least 800 yards. In the trials already made, every time a Zeppelinette target had been attacked by these incendiary shells it had been destroyed, in one case even when the target was 200 yd. behind the point of burst. The shell consisted of the service 3-in. 20-cwt. (universal) shrapnel body, the tin cup and disc being omitted and replaced by a central brass tube attached to the fuse hole, the brass tube being filled with ophorite and the body of the shell with thermit. A similar type of shell was being considered for use with 13-pdr. 6-cwt. and 9-cwt. guns.[2]

The 13-pdr. design was provisionally approved, but on 12 August the approval had to be suspended.[3]

The Army Council had asked (26 July) that 40 per cent. of all the ammunition supplied for anti-aircraft guns should be incendiary, but on 9 August the proportion asked for was reduced to 25 per cent.,[4] and it was stated that the Commander-in-Chief in France was anxious to receive the new design of incendiary shell for the 3-in. 13-pdr. and 12-pdr. anti-aircraft guns.[5]

The Army Council was informed (30 August) that the types of incendiary shell then in existence were intended primarily for attacking Zeppelins, and it was doubtful whether they could be successfully used against aeroplanes, and was asked whether it wished to modify the proportions for issue to France. A different type of shell for attacking aeroplanes was being considered, but the anti-Zeppelin type was being given precedence.[6]

Thereupon the Army Council consulted the Commander-in-Chief in France, who stated that he would prefer a fixed number of incendiary shells to the provision of a periodical percentage of them, and asked for a total provision of 150 rounds for each of the 100 guns in the second line and on lines of communication, 90 of which were 3-in. 20-cwt. guns and 10 of which were 12-pdr. 12-cwt. guns.[7]

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[1] The approval was dated 7 June, 1916. D.G.M.B./S./1066.

[2] D.M.R.S./138. All these anti-Zeppelin shells were to be marked A.Z. O.C. Min. 7599. D.G.M.D./S./836.

[3] D.D.G.O./685 and O.C. Minute 6834.

[4] 75/12/9383 (A1) in D.M.R.S./356.

[5] 75/12/9383 in D.M.R.S./138.

[6] D.M.R.S./138.

[7] 75/12/9383 (2 Sept.) in D.M.R.S./138.

It was therefore arranged (24 November, 1916) that 1,000 rounds of this anti-Zeppelin incendiary ammunition should be issued for trial in the 13-pdr. 9-cwt. anti-aircraft guns in France with a view to discovering whether this type of ammunition was suitable for use against aeroplanes. The ammunition was issued to the War Office on 1 January, 1917.[1] Another type of anti-Zeppelin ammunition filled with a new composition was supplied from the summer of 1917 onwards.[2]

Smoke Shell.

On 23 February, 1917, the 3-in. 20-cwt. powder-filled shell was approved for use for anti-aircraft practice, and 500 were ordered (26 February), a quarterly requirement for this shell being issued on 10 April as follows :—

3-in. 20-cwt.	900
	500 already ordered
12-pdr. 12-cwt.	150
13-pdr. 9-cwt.	250
18-pdr.	360

By 16 June the first quarter's requirement had been completed.[3]

Early in 1918 (21 February) the War Office asked that the output of Target shell filled with a smoke mixture might be hastened.[4] There had been some difficulty over the gauges for these shells, but it was hoped (18 March) to issue 10,000 3-in. smoke shells in May.[5] These shells filled with smoke mixture were much preferred by the Home Forces to shells filled with powder, and it was considered desirable to discontinue the latter.[6]

On 2 June the Air Ministry asked for an immediate supply of 1,000 rounds per month of the 13-pdr. 9-cwt. Target shell, stating that in future they would require 1,200 rounds per month.[7] Before the end of the month (29 June) 1,000 rounds were delivered to the Deputy-Director of Ordnance Stores and arrangements made for the supply of 1,200 rounds per month.[8] On 13 July an increased programme of future requirements was issued. Including the 1,200 per month already ordered, the following rounds of 13-pdr. 9-cwt. were required :—

For France	2,600 rounds per month.
„ Air Ministry	2,000 „ „
„ Home Forces	200 „ „
„ Stock	200 „ „
Total	5,000

[1] D.M.R.S./138.
[2] (Printed) *Weekly Report*, No. 91, II (12/5/17); *Ibid.*, No. 111 (29/9/17). For further details of Dr. Whiteley's composition and other incendiary compositions, *see* Vol. XI. Part II.
[3] D.M.R.S./138 B.
[4] War Office/Gen. No./6591/A.2 C. D.M.R.S./138 P.
[5] D.M.R.S./138 P.
[6] *Ibid.* War Office/Gen. No./6591 A.2 C.
[7] War Office 87/Stores/3759 (A.2). D.M.R.S./138 P. A new design of Smoke Target Shell was adopted in December, 1917. (Printed) *Weekly Report*, No. 122, II (15/12/17).
[8] D.M.R.S./138 P.

In addition, 3,500 rounds of smoke shell for the 3-in. 20-cwt., which included the 600 already ordered for home defence, were required monthly. Deliveries were to be made as quickly as possible.[1]

On 8 August there was a further request for these shells from the Air Ministry, who were proposing to inaugurate three or four meteorological stations where they would use 13-pdr. 9-cwt. for obtaining wind velocities. Their previous order for 2,000 per month was increased to 4,000. This brought the total requirements of 13-pdr. 9-cwt. smoke shell up to 7,000 rounds per month.[2] The demand for other natures of smoke shell stood as follows :—

3-in. 20-cwt.	3,500 per month
12-pdr. 12-cwt.	200 quarterly
18-pdr.	500 „
75 mm.	150 „

It was understood that the increased manufacture would not affect the delivery of other natures.[3]

On 27 March, 1918, a design of 12½-lb. special shrapnel was approved for use with 3-in. 20-cwt. It contained 50 bullets and was filled with phosphorus.

The following month (11 April) there was a special requirement of

10,000 rounds for 13-pdr. 9-cwt.
1,500 „ „ 3-in. 20-cwt.

for trial in France.[4]

The Admiralty were asked (13 April) if they could supply the latter, as the shells were wanted for use in the course of two or three weeks, but they were unable to help.

STAR SHELLS.

The experience of the French during the various attacks by Zeppelins on Paris showed that star shells were of great use both in illuminating the target and indicating the course which defending aeroplanes should take.

On 27 March, 1916, G.H.Q. Home Forces asked for a supply of star shell for 6-pdr. guns, stating that 6-pdr. guns could be utilised solely for the purpose of firing these star shells as soon as 3-in. and 12-pdr. guns were delivered in sufficient quantities.[5] The Design Department suggested that trials should be undertaken in order to ascertain the effect of ammunition of this kind in such a small size before any large order was placed.[6] The Ordnance Committee asked the Chief Superintendent of Ordnance Factories for a design on 3 April, received it on 15 April, and asked the Chief Superintendent of Ordnance

[1] W.O. 121/1/523 (A.2 C) in D.M.R.S./138 P.
[2] *Ibid.*
[3] *Ibid.*
[4] W.O. 121/1/475 (A.2 C). D.M.R.S./138 P.
[5] D.G.M.D./S./395.
[6] O.C. Minute 3116.

Factories to manufacture a trial order. Trials of this shell were begun. A little later the Director of Aerial Equipment was asked for a supply of rockets or star shell to rise 5,000 ft. at least for signalling purposes from observation posts in connection with the scheme for home defence against hostile aircraft at night (12 July, 1916). He stated that rockets to rise 5,000 ft. were not made, and could not be produced without considerable research, but that star shell would be supplied as soon as possible. The Director of Aerial Equipment asked whether star shell visible from 10 miles in clear weather could be produced, and later (2 August, 1916) asked that the trials of 6-pdr. star shell should be expedited, as the use of such a shell would be of the greatest value to the Home Defence squadrons.[1]

Trials proceeded without any very satisfactory result being reached, until on 18 October the Ordnance Committee was able to recommend a design for use in 6-pdr. Q.F. gun which should meet the requirements of G.H.Q. for illuminating Zeppelins and indicating the course that defending aeroplanes should take, while it should also meet the conditions of signalling by night asked for by Home Defences. The Committee recommended No. 65 (A) fuse for use with this shell. The shell contained eight stars and was calculated to attain a maximum height when fired vertically of about 12,500 ft., the time of flight being about five seconds.[2] Another request for a supply of 6-pdr. star shell to assist aeroplanes when searchlights could not penetrate the ground mist was received from G.H.Q. Home Forces on 14 December. Later trials with the same design, slightly modified and, it was hoped, improved, were most unsatisfactory, and on 26 February, 1917, the Design Department informed the Director of Artillery that a design for 6-pdr. star shell could not yet be approved, though it was hoped that the excellent star effect observed in the earlier trials might again be obtained. The Design Department on 26 April asked that the 6-pdr. trials should be pushed on.[3] On 21 June the Design Department stated that it appeared to be useless to continue trials of this design (R.L. 25103), as there was no prospect of an early recommendation being made. An amended design (R.L. 26096), which was for a single star and parachute,[4] was adopted later. Star shell for the 13-pdr. (9 cwt.) gun and for the 3-in. gun was supplied in small quantities in the third quarter of 1918.

V. Supply Difficulties.

The production of anti-aircraft ammunition of so many different types and in comparatively small quantities naturally presented many difficulties from the supply point of view.

The War Office on several occasions asked the Ministry to hasten supply. Thus on 23 March, 1916, the Commander-in-Chief telegraphed

[1] Ordnance Committee Minutes 6390, 6971.

[2] Ordnance Committee Minute 9183.

[3] A design for 3-in. star shell already existed, and a design for 18-pdr. star shell was approved in March, 1918. (Printed) *Weekly Report*, No. 134, II (16.3.17).

[4] Ordnance Committee Minute 17824.

that there were only 241 rounds of 3-in. 20-cwt. gun ammunition per gun and only 187 rounds per gun for 13-pdr. 9-cwt. guns,[1] and that it had already been necessary to draw on the cavalry echelons in order to maintain the supply of ammunition for other 13-pdr. anti-aircraft guns. It appeared that a shortage of boxes had held up supplies of shrapnel for the 3-in. 20-cwt. gun, but it was hoped that 500 rounds a week could be supplied together with 1,000 rounds of H.E. and 1,000 rounds of shrapnel for the 13-pdr. 9-cwt. gun.[2]

A serious fire at Audruiq destroyed all line of communication stock, and on 28 July, 1916, the Commander-in-Chief in France telegraphed that ammunition was urgently required for the 3-in. 20-cwt. guns,[3] and to meet this demand 2,000 rounds fitted with long burning fuses were handed over to the Deputy-Director of Ordnance Stores on 31 July.

The Director of Artillery on 12 September called attention to a considerable falling off in output of 12-pdr. and of 3-in. anti-aircraft gun ammunition during the week ending 9 September, 1916, only 716 rounds of 12-pdr. and 2,628 of 3-in. 20-cwt. having been received by the Deputy-Director of Ordnance Stores.

Shrapnel ammunition for the 3-in. 5-cwt. gun was supplied on a contract held by the Elswick Ordnance Company, dated 25 July, 1915,[4] and on 21 January, 1916, in response to a " hastener " from the front, Mr. West was asked to press for the delivery of this ammunition at the earliest possible moment as it was urgently wanted.[5] The firm promised delivery at the rate of 1,000 a week, beginning in the first week in February. The Director of Artillery asked that a second contract held by the firm for 6,000 shrapnel shell for this gun should be turned over to H.E. shell,[6] and this was arranged, the empty H.E. shell together with the filled night-tracer being supplied by the Ministry, Armstrongs providing the other components and filling the shells, while the Thames Ammunition Works assembled the complete rounds.[7] Delivery of 996 rounds of this H.E. shell was expected in October, and by 2 November 2,000 rounds had been handed over to the Deputy-Director of Ordnance Stores.

In October the War Office stated that no more shrapnel for these guns would be required after the delivery of the 6,000 complete rounds ordered on 25 July, 1915, and the guns were later supplied with H.E. and incendiary shell in equal proportions.[8]

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[1] D.M.R.S./138.

[2] Minute by D.D.G. (C), 25 March. D.M.R.S./138.

[3] A.1/361/16 in D.M.R.S./138.

[4] 94/G./215.

[5] D.M.R.S./W.O.R./315.

[6] 121/Stores/3791, dated 7 Jan., 1916, 11 March, 1916, A./1/107/1916.

[7] 4 May, 1916. D.M.R.S./W.O.R./315.

[8] *Ibid.*

6-pdr. Anti-Aircraft Gun Ammunition.

There were serious but unavoidable delays in the supply of 6-pdr. anti-aircraft ammunition, which had been asked for at the end of 1915. A new design had to be prepared, and it was not until May, 1916, that arrangements were made for the manufacture of 150,000 6-pdr. anti-aircraft shell by the Ordnance Factories and by the trade. It was not easy to obtain steel castings for this shell which would give a satisfactory fragmentation. In May, June, and July tests were being carried out at Woolwich, and finally steel made by Edgar Allen & Company was forwarded to Keighley National Shell Factory and the Phœnix Manufacturing Company, who were making this type of shell. Further delay was caused by lack of gauges.

An additional requirement for 100,000 of these shells was received on 12 August.[1]

The Ministry reported on 26 September, 1916, that difficulties had been experienced in manufacturing this type of shell, but supplies of empty shell were being received by the filling factory, and it was hoped that deliveries to the War Office would begin in a few weeks' time.[2]

3-in. 20-cwt. Shell.

When ammunition for the 3-in. 20-cwt. gun was first asked for in the summer of 1915, the design for the H.E. shell had not been evolved and that for the shrapnel shell was not considered satisfactory.[3] It was not until 6 January, 1916, that designs were approved.[4] Orders were placed at once, but deliveries did not begin until April.

At the end of 1917 (19 December) the supply of 3-in. 20-cwt. ammunition was threatened by a shortage of fuses 85/44 and 185. These came from America and were being rejected at the rate of 75 per cent. and more.[5]

The situation continued to be unsatisfactory for some months, and by 17 April, 1918, stocks of 12,000 rounds intended for France had been diverted for home use. These had to be made good, and as the American fuses were then beginning to improve it was hoped that the 13,000 rounds could be repaid at the rate of 5,000 per week, beginning at once. At the same time (3 April), as the existing stock of full charge H.E. for Home Defence was only about 15,000 instead of 50,000, arrangements were made to hasten output to the limit of fuses, which would probably be 10,000 per week, and this rate of filling was reached at the beginning of May. The stock of barrage ammunition was satisfactory.[6]

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[1] (Printed) *Weekly Report*, No. 40, Section III. (6.5.16); No. 41, Section III. (13.5.16); No. 44, Section III. (3.6.16); No. 48, Section III. (1.7.16); No. 49, Section III. (8.7.16); No. 54, Section III. (12.8.16).

[2] D.M.R.S./138.

[3] D.M.R.S./W.O.R./84.

[4] D.M.R.S./W.O.R./535.

[5] D.M.R.S./138 B.

[6] W.O. Gen. No./6591 (A.2 C), D.M.R.S./138 P.

4-IN. MK. IV SHELL.

In October, 1917, 600 rounds H.E. full charge and 400 reduced charge had been ordered for the 4-in. gun at Shoeburyness, but by 11 January, 1918, only 59 had been supplied and the War Office complained that apparently no effort was being made although the demand was urgent.[1] The Ministry replied (31 January) that another 43 rounds had been delivered during January, making a total of 102, that they hoped to issue 200 more in March and meet the full requirement before the end of May. The delay was due to the difficulty in manufacture of the cartridge cases, for which the Ministry had no plant, but by the courtesy of the Admiralty they were to have the use of plant then being installed at the Ordnance Factories. A further delay was caused in May by the discovery of impurities in the varnish of the shell. This was soon rectified, and it was hoped that the full requirement would be completed very shortly.[2]

4-IN. MK. V SHELL.

The demand for 4-in. Mk. V shell dates from 30 November, 1917, when the War Office asked for 1,000 rounds of this shell for each of the 100 equipments ordered at the same time—500 rounds per gun as an initial supply and 500 as soon after as possible. In addition to these supplies for service 500 rounds were required for range and accuracy trials.

On 23 January, 1918, 100 rounds per gun of A.2 ammunition was ordered for experimental purposes. The manufacture of the cartridge case for this shell presented difficulties, as it was too long for any existing plant but that used by the Admiralty at the Ordnance Factories; and although the Admiralty allowed the Ministry the use of this plant production was necessarily slow. By 13 February, 100 rounds of H.E. had been issued and 200 more were expected the following month.

On 16 April the first of the guns were due, but the supply of ammunition was held up on account of difficulties with gauges. It was hoped, however, to bond 1,000 before the end of May. Later (2 August) another danger threatened—a shortage of boxes, but in the course of a few weeks (20 August) this was overcome. On 11 June the Admiralty asked for a supply of this shell, but very little could be spared as there were now several guns in use at home and overseas. It was found that out of the July deliveries of 1,500, 500 only could be handed over.[3]

It was now obvious (15 June) that the plant existing in the country was not sufficient to meet the increased requirement, and financial sanction was sought for the installation of new plant and extensions to buildings.[4]

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[1] W.O. 57/Eastern/5793 A.2 in D.M.R.S./138 P.

[2] 7 May, 1917; D.M.R.S./138 Y.

[3] D.M.R.S./138 Z.

[4] (Printed) *Weekly Report*, No. 146, Section VI.A (15.6.18).

12-pdr. 12-cwt. Anti-Aircraft Ammunition.

The early failures with anti-aircraft ammunition were due to the lack of a suitable fuse, and when these had been overcome the ammunition supplied was very satisfactory. One or two exceptions to this may be noticed.

On 12 September, 1916, the War Office reported that a very large percentage, nearly one-third, of the 12-pdr. anti-aircraft ammunition supplied by the Ministry was found to be over-gauge.[1] The explanation given by the Ministry (26 September) was that there had been great difficulty in obtaining enough chamber gauges for this ammunition, and the ammunition was therefore sent to be tried in the gun. Since the beginning of September all the ammunition provided had been gauged in a gun, and it was suggested that all the ammunition already issued should be tried in the gun for which it was appropriated, any found unsuitable being returned to store for rectification.[2]

10-pdr. Anti-Aircraft Ammunition.

The War Office reported on 12 September that the cartridge cases for 10-pdr. ammunition did not appear to come up to design dimensions, which would make it necessary to adjust the base of the shell and cause delay in getting the guns of this type—a number of which were nearly ready for issue—into action.[3] It appeared that a number of cartridge cases had been handed over by the Admiralty in very bad condition.[4]

A more important defect was the supply of unsatisfactory primers, which caused missfires when the guns in the London area defences were brought into action in October, 1916, and in the guns in the Northern command in June, 1917.[5] In the latter case the defective primers were made at Woolwich.

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[1] 71/1/5385 (A.1) in D.M.R.S./138.

[2] D.M.R.S./138.

[3] 71/1/5385 (A.1) D.M.R.S./138. D.M.R.S./359.

[4] D.M.R.S./138 A.

[5] D.G.M.D./A./202. D.M.R.S./128 B.

APPENDIX.

APPENDIX.

Deliveries of Anti-Aircraft Guns

		1914.		1915.				1916.			
——		Aug. and Sept.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.
Anti-Aircraft Guns (New)—											
13-pdr., 9 cwt., I–IV ..		—	—	—	—	1	1	26	112	69	31
3-in., 5 cwt.		—	—	—	—	6	6	2	—	—	—
3-in., 20 cwt., I–III ..		—	—	—	—	—	—	—	20	52	89
4-in., A.A.		—	—	—	—	3	7	—	—	—	—
Total		—	—	—	—	10	14	28	132	121	120
Anti-Aircraft Guns (Repaired)—											
13-pdr., 9 cwt.		—	—	—	—	—	—	—	—	—	4
3-in., 5 cwt.		—	—	—	—	—	—	—	—	—	—
3-in., 20 cwt.		—	—	—	—	—	—	—	—	—	—
Total		—	—	—	—	—	—	—	—	—	4
Anti-Aircraft Ammunition—											
6-pdr.		—		—	—	—	—	—	—	—	4,600
12-pdr., 12 cwt. (3-in. shell)	H.E. ..	—		—	—	—	—	2,400	—	22,600	4,100
	S. ..	—		—	—	—	—	—	—	—	—
	Incy.	—		—	—	—	—	—	—	—	—
13-pdr., 6 cwt. (13-pdr., or 3-in. shell)	H.E. ..	—		—	—	—	—	4,000	41,800	19,200	10,100
	S. ..	—		—	—	—	—	—	—	—	—
	Incy.	—		—	—	—	—	—	—	—	—
13-pdr. 9 cwt. (13-pdr., or 3-in. shell)	H.E. ..	—		—	—	—	—	1,000	18,200	111,800	154,400
	S. ..	—		—	—	—	—	6,500	74,700	187,400	258,300
	Incy.	—		—	—	—	—	—	—	—	—
	Star. ..	—		—	—	—	—	—	—	—	—
3-in., 5 cwt. ..	H.E. ..	—		—	—	—	—	—	—	—	—
	Incy.	—		—	—	—	—	—	—	—	—
3-in., 20 cwt. (3-in., or 13-pdr. shell)	H.E. ..	2,600		—	1,200	100	2,100	—	13,900	65,500	92,300
	S. ..	—		—	200	200	100	200	6,900	33,900	25,600
	Incy.	—		—	—	—	—	—	—	—	—
	Star ..	—		—	—	—	—	—	—	—	—
18-pdr. ..	H.E. ..	—		—	—	4	—	—	10,200	28,000	6,800
	S. ..	—		—	—	—	—	—	—	—	—
	Incy. A.Z.	—		—	—	—	—	—	—	—	—
4-in., Mark IV	H.E. ..	—		—	—	—	—	—	—	—	—
4-in., Mark V	H.E. ..	—		—	—	—	—	—	—	—	—
Total		2,600		—	1,400	300	2,200	14,100	165,700	468,400	556,200

* Includes some ordinary 18-pdr. shell

APPENDIX.

and Ammunition, 1914–1918.

1917				1918.					
1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	Oct. and 1-11 Nov	12 Nov. to 30 Dec.	Total.
68	57	51	117	46	69	64	6	6	724
—	—	—	—	—	—	—	—	—	14
15	29	23	5	34	54	116	72	32	541
—	—	5	1	—	12	20	7	—	55
83	86	79	123	80	135	200	85	38	1,334
10	21	51	80	44	51	37	2	2	302
—	1	—	—	—	1	1	—	—	3
—	1	4	11	16	10	4	7	—	53
10	23	55	91	60	62	42	9	2	358
12,000	—	—	—	—	—	—	—		16,600
—	—	4,800	7,100	3,900	100	—	—		45,000
—	—	1,700	100	—	—	—	—		1,800
500	—	1,900	12,400	2,000	—	—	—		16,800
9,200	32,200	45,700	41,600	24,700	—	—	—		228,500
300	—	15,900	21,600	10,200	8,200	—	—		56,200
—	—	1,800	—	—	—	—	—		1,800
173,300	224,400	292,200	489,600	289,800	426,000	171,300	106,500		2,458,500
83,100	77,600	93,100	113,000	169,500	91,700	125,300	81,200		1,361,400
1,000	2,900	8,100	15,400	—	—	6,000	—		33,400
—	—	—	—	—	—	100	—		100
1,400	3,700	3,700	300	300	—	—	—		9,400
—	—	800	3,700	—	—	—	—		4,500
27,300	—	26,200	271,300	134,100	192,100	110,100	38,000		976,800
30,500	—	300	22,300	6,700	38,600	50,500	24,100		240,100
14,100	3,300	17,800	20,200	900	9,000	5,400	4,800		75,500
—	—	—	—	—	—	100	300		400
8,000	20,800	1,300	71,300	300	—	—	—		146,700*
—	—	500	—	—	—	7,100	—		7,600*
2,700	—	46,300	16,800	8,300	4,600	—	—		78,700
—	—	—	—	—	400	—	—		400
—	—	—	—	—	500	1,500	10,400		12,400
363,400	364,900	562,100	1,106,700	650,700	771,200	477,400	265,300		5,772,600

filled for anti-aircraft purposes.

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